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81-5-103
DEC ID 8950003.1
on-Refuge

Contaminant Levels in the Sudbury River, Massachusetts

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May, 1991

Report Number RY91-NEFO-2-EC

RPT 195

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PREFACE

Information presented in this report is final documentation of the 1986, 1987, and 1989 environmental contaminants evaluation of sediments and biota from the Sudbury River and Great Meadows National Wildlife Refuge under Regional ID Numbers R5-85-016, R5-87-011, and 89-5-103. Study design, implimentation, data analysis, and reporting were completed by Environmental Contaminants personnel in the New England Field Offices, U.S. Fish and Wildlife Service, Department of the Interior. Funding for the project was provided by the division of Enviromemtal Contaminants and the division of Refuges and Wildlife.

Questions, comments, and suggestions related to this report are encouraged. Written enquiries should refer to Report Number RY91-NEFO-2-EC and be directed to the Service at the following address:

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INTRODUCTION

Great Meadows National Wildlife Refuge sits astride the Concord and Sudbury Rivers in portions of the towns of Bedford, Billerica, Lincoln, Carlisle, Concord, and Sudbury, Massachusetts, which are suburban communities that lie west of the Boston Metropolitan area. Due to the suburban context of the refuge, the potential risk of pollution affecting the refuge is high. Both the Sudbury and Concord Rivers may receive contaminant loadings from a variety of sources, including industrial effluents, sewage treatment effluents, road runoff, and landfill leachate. There are also at least two Superfund sites in the watershed; the Nyanza site in Ashland and Hocomonco Pond in Westborough. The potential for any or all of these sources of pollution to adversely affect the refuge stimulated the U.S. Fish and Wildlife Service's interest in determining if the refuge has been impacted by contaminants, and evaluating the extent of injury.

In 1986, a screening survey was conducted by analyzing fish captured in major sediment depositional areas of the Sudbury, Assabet, and Concord Rivers. Figure 1 shows the location of these river systems in Massachusetts. In 1987, more intensive sampling was conducted which included analyzing sediments and fish from a broader extent of the river systems, and analyzing small mammals and red-winged blackbird eggs from refuge property. In 1989, sediments were analyzed in specific locations as a "hotspot" assessment.

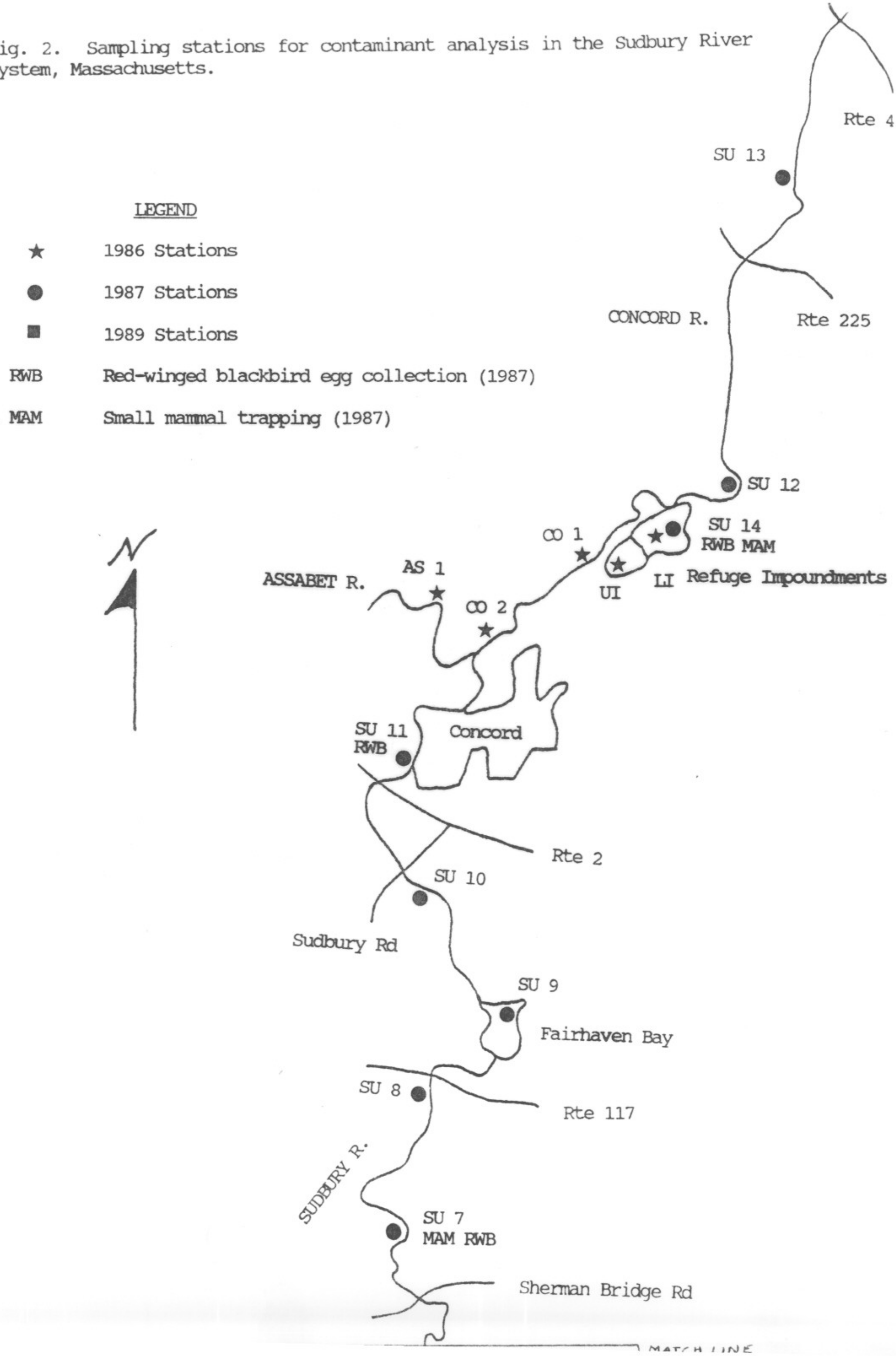
STUDY AREA

The Sudbury River originates in Cedar Swamp Pond, in Westboro, Massachusetts, which is a remote bog surrounded by wetlands. From here the river travels easterly through Southville and Ashland. In Ashland the river passes by the Nyanza Superfund Site, and then flows through two major impoundments (Reservoir No. 2 and Reservoir No. 1), which are reserve water supplies controlled by the Metropolitan District Commission. The river then bends northeasterly where it is impounded by the Saxonville Dam. In Sudbury and Wayland, the Sudbury River is bordered by wide emergent wetlands, most of which are within the boundaries of the Great Meadows National Wildlife Refuge. In Concord, the Sudbury joins the Assabet River, where they form the Concord River, which flows northerly toward the Merrimack River. In Concord and Lincoln, the Concord River is bordered by Great Meadows National Wildlife Refuge, including the refuges' managed waterfowl impoundments which lie within the floodplain of the river.

There are a number of small streams or brooks which feed into the Sudbury River. Two of these small brooks were incorporated into the sampling scheme. Wash Brook is a small order trout stream that runs through an emergent wetland, and enters the Sudbury River from the west just south of Rte 20. The old Wayland landfill is located just north of a portion of Wash Brook. An unnamed brook enters the Sudbury River from the east a short distance north of Rte. 20. For ease of discussion we have named this "Raytheon Brook" because the brook originates by the Raytheon Corporation plant. Figure 2 shows the sampling station locations for the three years of data collection.

Fig. 1. Map showing the locations of the Concord, Sudbury, Assabet, and Merrimack Rivers in Massachusetts.

Fig. 2. Sampling stations for contaminant analysis in the Sudbury River system, Massachusetts.



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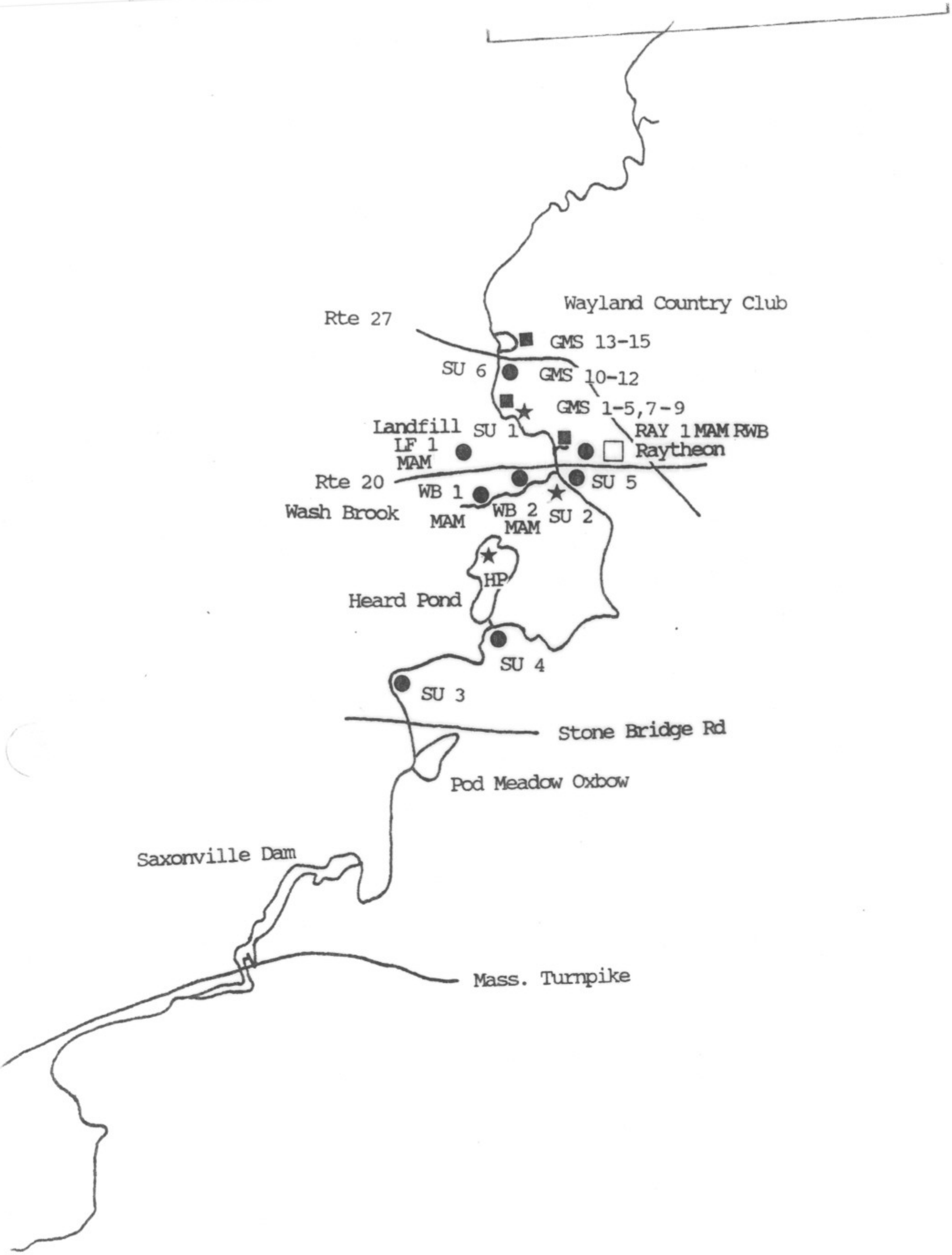

Wayland Country Club
Rte 27
GMS 13-15
SU 6
GMS 10-12
GMS 1-5,7-9
Landfill
SU 1
RAY 1 MAM RWB
LF 1
MAM
Raytheon
Rte 20
SU 5
WB 1
Wash Brook
MAM
WB 2
MAM
SU 2
HP
Heard Pond
SU 4
SU 3
Stone Bridge Rd
Pod Meadow Oxbow
Saxonville Dam
Mass. Turnpike

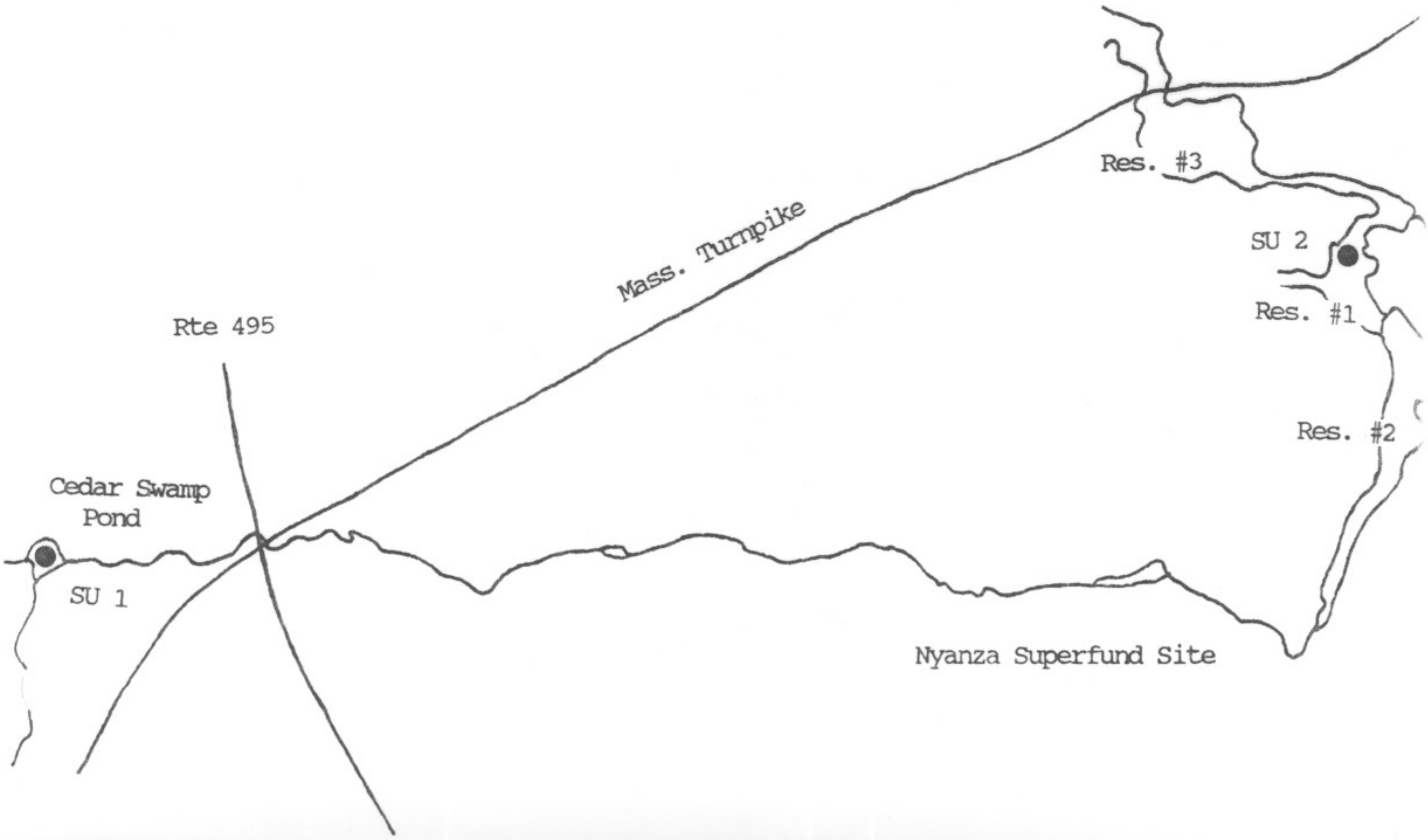
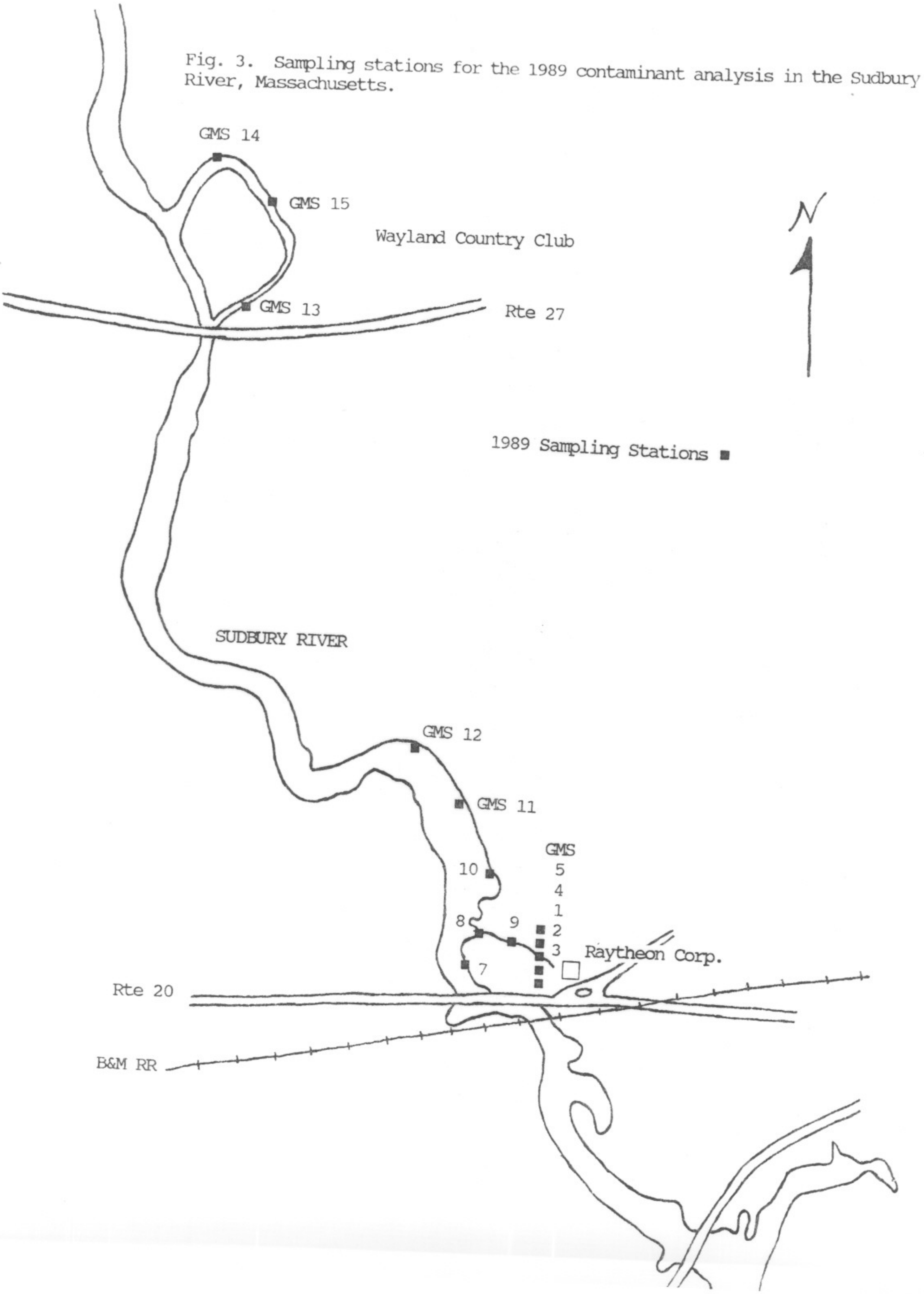

Res. #3
Mass. Turnpike
SU 2
Res. #1
Rte 495
Res. #2
Cedar Swamp
Pond
SU 1
Nyanza Superfund Site

Fig. 3. Sampling stations for the 1989 contaminant analysis in the Sudbury River, Massachusetts.



METHODS

1986 Sampling

Fish were collected from eight sampling stations in the Sudbury, Concord, and Assabet Rivers. Sites were chosen because of their location relative to the refuge (upstream or downstream), because of their importance to the refuge (impoundments), or because they are major sediment depositional areas in the river. Five species of fish were collected from the stations: yellow perch (Perca flavescens), white perch (Morone americana), brown bullhead (Ictalurus nebulosus), white sucker (Catostomus commersoni), and black crappie (Pomoxis nigromaculatus). Species were chosen based on availability and similarity of life histories. A sixth species, chain pickerel (Esox niger), was also collected from the refuge impoundments to represent a species at the top of the aquatic food chain.

Ten similar-sized fish of each species were collected by gill netting. Fish were wrapped in aluminum foil, frozen, and subsequently submitted for chemical analyses. Fish as wholebody composite samples were analyzed for heavy metals, PCBs, and organochlorine pesticides.

1987 Sampling

Sediments, fish, small mammals, and red-winged blackbird (Agelaius phoeniceus) eggs were collected for analyses from sites on the Sudbury and Concord Rivers. Sediments were collected from 17 stations. Sample site selection was based on juxtaposition to potential contaminant sources. Sediments were collected by Ekman dredge, homogenized in the field, and placed in acid-rinsed, solvent-rinsed glass jars. Samples were frozen for subsequent shipment for chemical analyses. Sediments were analyzed for PCBs, PAHs, organochlorine pesticides, and heavy metals.

Fish were collected from 13 stations by gill netting. Ten similar sized fish of each of three species were sampled. The species collected were yellow perch, white perch, and black crappie. Fish were prepared for shipping and analyses in the same manner as in 1986. Fish were analyzed for PCBs, PAHs, organochlorine pesticides, and heavy metals.

Small mammals were collected by snap trapping at eight stations. Species collected were meadow vole (Microtus pennsylanicus), meadow jumping mouse (Zapus hudsonius), and white-footed mouse (Peromyscus leucopus). One to seven mammals were collected per sample. Small mammals were wrapped in aluminum foil, and frozen for subsequent chemical analyses. Mammals (wholebody, fur-on) were analyzed for PCBs, PAHs, organochlorine pesticides, and heavy metals.

Red-winged blackbird eggs were collected from nests in four locations. Three to six eggs were collected per sample. Egg composites were analyzed for PCBs, PAHs, and organochlorine pesticides.

1989 Sampling

Sediments were collected from 14 stations (Figs. 2 and 3) with a stainless steel spatula that was solvent-rinsed between samples. Five stations formed a 50-foot transect perpendicular to "Raytheon Brook". The transect included a sample in the brook, and two samples, each, in wetlands north and south of the brook. Two more stations were sampled downstream in the brook, three samples were taken on the east bank of the Sudbury River, downstream of the mouth of "Raytheon Brook", and one sample was taken upstream of the mouth of the brook. Three additional samples were taken in an oxbow of the Sudbury River, downstream of "Raytheon Brook", adjacent to the Wayland Country Club. Sediment samples were analyzed for PCBs, PAHs, aliphatic hydrocarbons, organochlorine pesticides, and heavy metals.

Data Analysis

Analyses costs prevented the collection of quantities of data sufficient to allow for parametric statistical comparisons of samples. In instances where specific chemical criteria exist, contaminant concentrations in fish are compared to the United States Food and Drug Administration (FDA) action levels. However, these comparisons are made cautiously, since the action levels relate to the edible portion of the fish, and our data are for whole fish. Contaminant concentrations in sediments are compared to classifications developed by Bahnick et al. (1981) for sediments in harbors in the Great Lakes.

RESULTS

1986 Sampling

Fish

PCBs and Organochlorine Pesticides:

Total PCBs were found in **whole fish** to be elevated above the FDA action level for the **edible portion** at five out of eight stations (Table 1). At stations CO1 and AS1, PCBs in white perch and white sucker, respectively, were found to equal the 2.0 ppm FDA action level. Only the fish in the refuge impoundments appeared to be relatively free of PCB contamination. Levels of PCBs ranged from a low of 0.10 ppm in brown bullhead at station UI (refuge impoundment), to a high of 6.62 ppm in white perch at station HP (Heard Pond). No trend within species is visually evident (Fig. 4).

Levels of dieldrin in whole yellow perch slightly exceeded the FDA action level for the edible portion at two stations, SU1 and HP (Table 2), although other species at these locations did not exceed the FDA criterion for dieldrin (Fig. 5). No other organochlorine pesticides were found in notable concentrations in fish flesh in our 1986 samples (Append. 1).

Table 1. Total PCBs (ppm wet weight) in fish collected in 1986 from the Sudbury, Concord, and Assabet Rivers in Sudbury and Wayland, Massachusetts.

STATION	YELLOW PERCH	WHITE PERCH	BROWN BULLHEAD	BLACK CRAPPIE	WHITE SUCKER	CHAIN PICKEREL
SU1	3.75*	3.37*	1.14	-	-	-
SU2	1.94	2.57*	-	-	-	-
CO1	1.28	1.99*	-	-	-	-
CO2	2.41*	3.30*	1.39	2.29*	-	-
AS1	1.98*	1.25	-	-	3.00*	-
LI	0.60	-	0.31	-	-	-
UI	-	-	0.10	-	-	0.36
HP	3.28*	6.62*	2.84*	2.57*	-	-

- NO DATA

* Equals or exceeds FDA action level for PCB's (2.0 ppm) in edible portion of fish. Samples are whole fish.

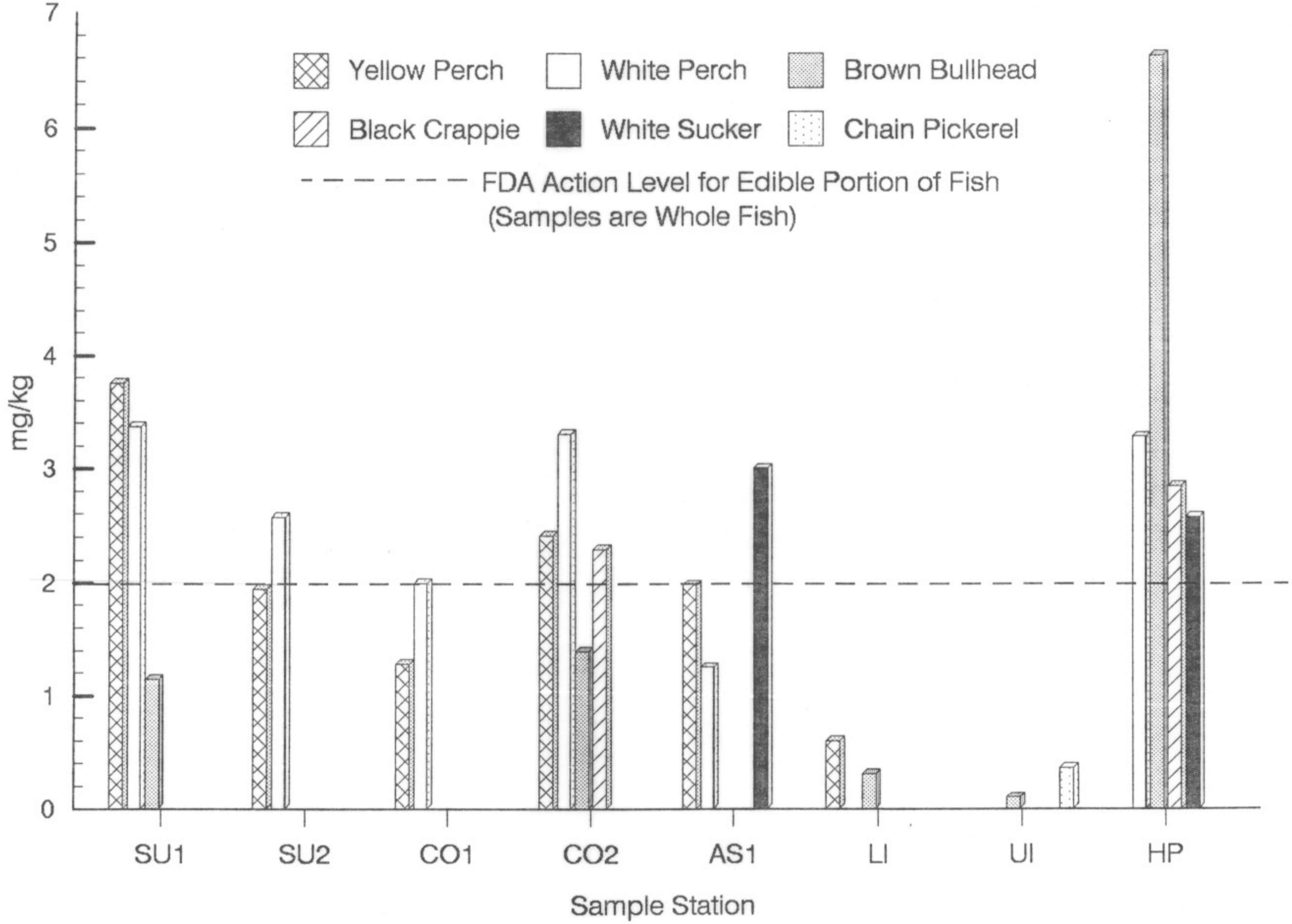


Fig. 4. Total PCB levels in fish (ppm WW) collected from the Sudbury, Assabet, and Concord Rivers in 1986.

Table 2. Dieldrin (ppm wet weight) in fish collected in 1986 from the Sudbury, Concord, and Assabet Rivers in Sudbury and Wayland, Massachusetts.

STATION	YELLOW PERCH	WHITE PERCH	BROWN BULLHEAD	BLACK CRAPPIE	WHITE SUCKER	CHAIN PICKEREL
SU1	0.33*	0.18	0.14	-	-	-
SU2	0.15	0.22	-	-	-	-
CO1	0.10	0.11	-	-	-	-
CO2	0.13	0.24	0.06	0.14	-	-
AS1	0.10	0.04	-	-	0.09	-
LI	0.01	-	0.01	-	-	-
UI	-	-	0.01	-	-	0.01
HP	0.32*	0.20	0.06	0.13	-	-

\- NO DATA

* Exceeds FDA action level for dieldrin (0.3) in edible portion of fish. Samples are whole fish.

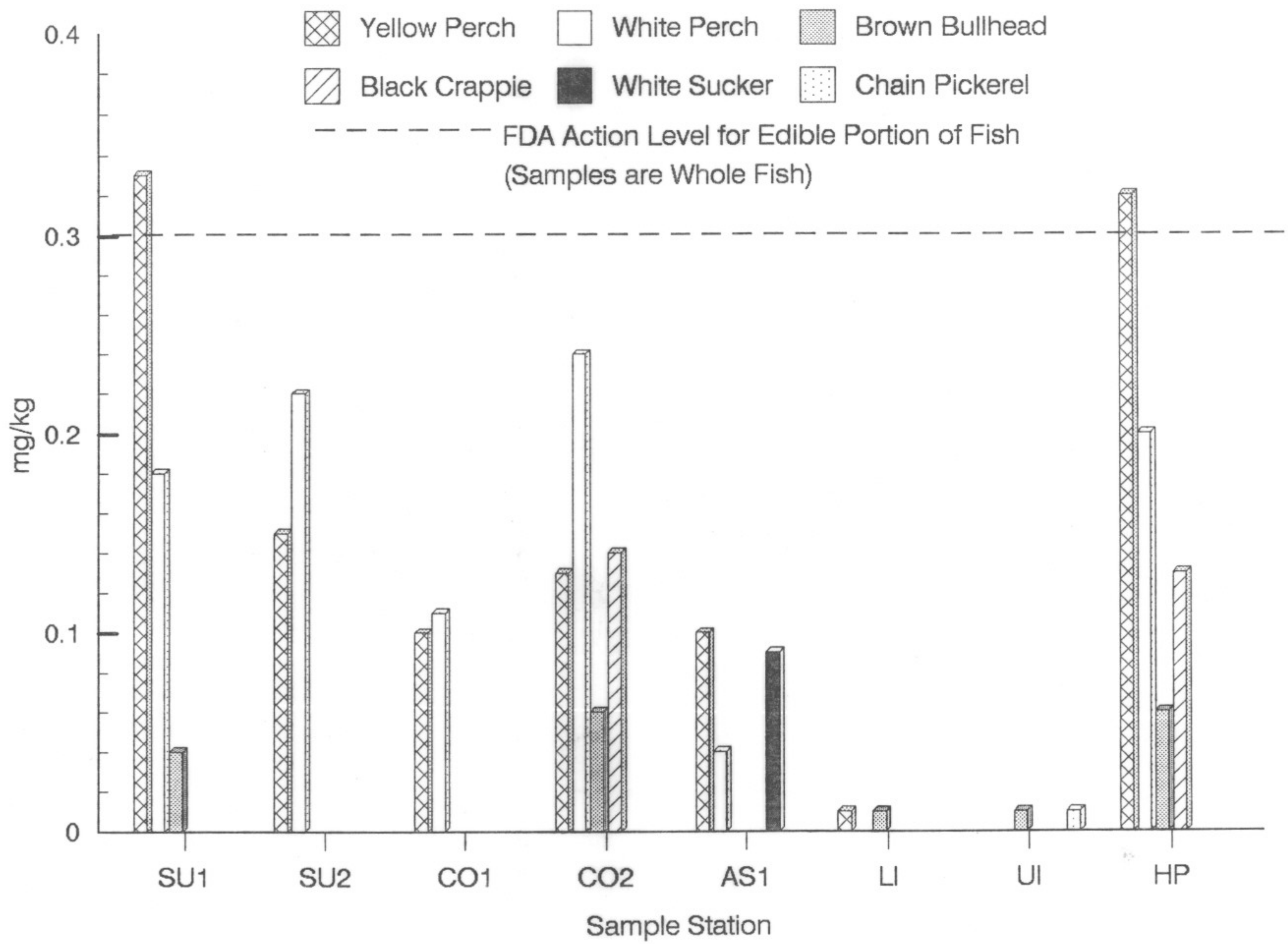


Fig. 5. Dieldrin levels in fish (ppm WW) collected from the Sudbury, Assabet, and Concord Rivers in 1986.

Metals:

None of the fish sampled carried concentrations of heavy metals which exceeded FDA action levels. However, the levels of lead in fish collected at stations SU1, CO1, CO2, AS1, and HP were notably higher than at SU2 and at the refuge impoundments, LI and UI (Fig. 6). Fresh weight lead levels ranged from a low of 0.05 ppm in chain pickerel at station UI to a high of 0.88 ppm in yellow perch and white perch at stations AS1 and CO1, respectively (Table 3). No trend within species is visually evident.

Wet weight concentrations of mercury in whole fish from the 1986 survey are generally less than 0.5 ppm (Table 4). Arsenic concentrations in whole fish are less than 0.1 ppm (Table 5). All heavy metal concentrations in the fish are listed in appendix 2.

1987 Sampling

Sediment

Organic Compounds:

Total PCB concentrations in sediments were found at detectable levels at five stations, but only station Ray 1 exceeded Bahnick et al.'s threshold for heavily polluted sediments (10 ppm). At stations SU3, SU4, SU8, and SU10, sediment PCB levels ranged from 0.90 to 1.31 ppm. The level at RAY1 was 17.92 ppm (Table 6; Fig. 7).

Organochlorine pesticides were not detected in sediments in notable concentrations. Dieldrin was only detected at one station(SU3), and at the level relatively low level of 0.04 ppm. Pesticide residues are reported in appendix 3.

PAHs were found at detectable levels at all sample stations. Concentrations ranged from 0.97 to 12.45 ppm at 16 of the 17 stations. The level at RAY 1 was notably higher at 166.53 ppm (Table 6; Fig. 8). Bahnick et al. do not provide classifications for PAH's.

Aliphatic hydrocarbons were detected in low amounts at all stations. However, notably higher concentrations were found at RAY1 and LF (Append. 4).

Metals:

Levels mercury, arsenic, lead, cadmium, and chromium are reported in table 6. Other metals are reported in appendix 5.

Mercury was found at levels which exceeded Bahnick et al.'s threshold for heavily polluted sediments (1.0 ppm) at 10 of 17 stations. At 16 of the 17 stations, levels ranged from 0.14 ppm (WB1) to 2.04 ppm (SU3). However, the 16.4 ppm level at station SU2 was dramatically higher than other Sudbury River sediment mercury concentrations (Fig. 9).

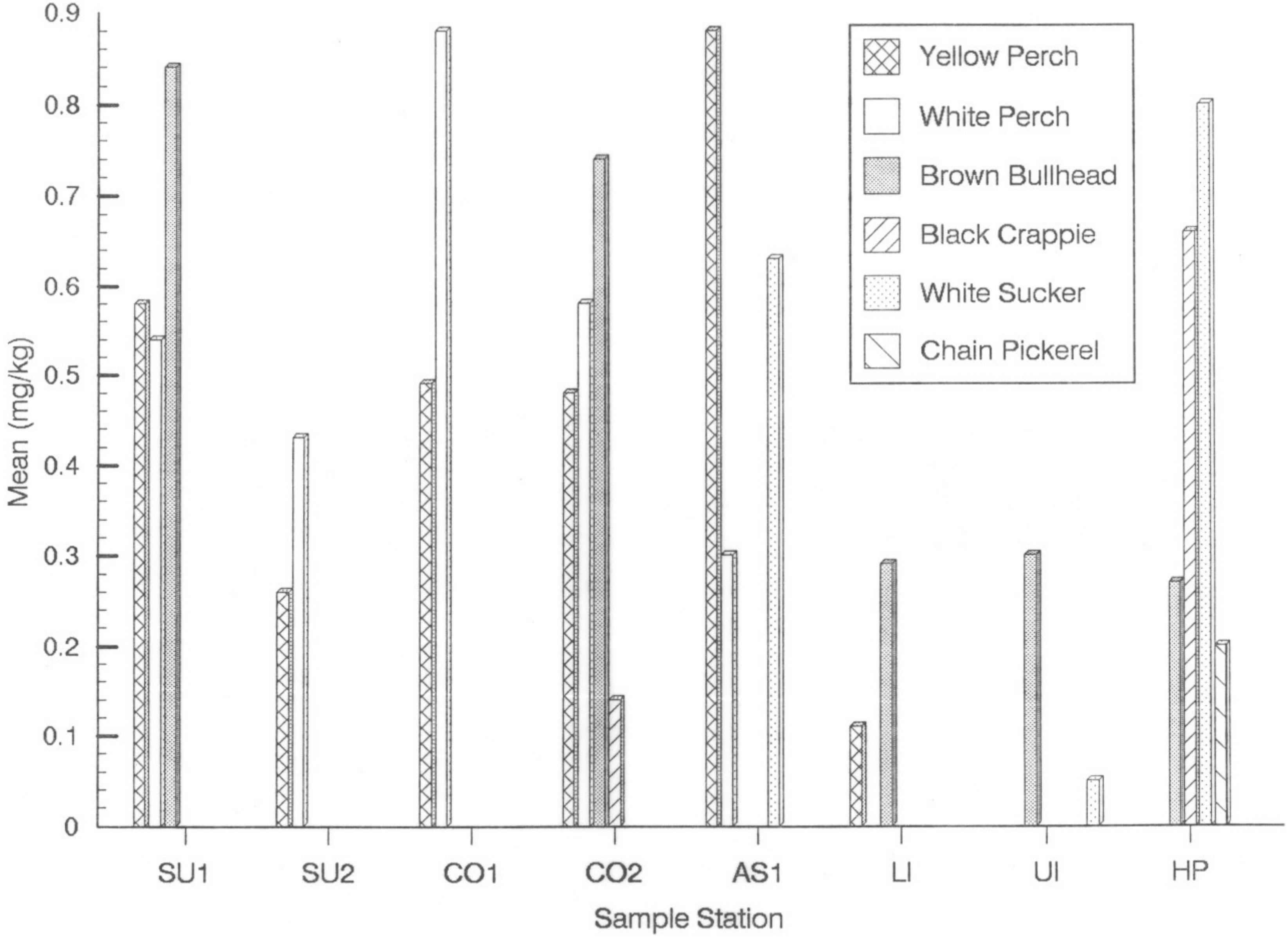


Fig. 6. Lead levels in fish (ppm WW) collected from the Sudbury, Concord, and Assabet Rivers in 1986.

Table 3. Lead (ppm dry weight and wet weight) in fish collected in 1986 from the Sudbury, Concord and Assabet Rivers in Sudbury and Wayland Massachusetts.

STATION	YELLOW PERCH		WHITE PERCH		BROWN BULLHEAD		BLACK CRAPPIE		WHITE SUCKER		CHAIN PICKEREL	
	DW	WW	DW	WW	DW	WW	DW	WW	DW	WW	DW	WW
SU1	1.70	0.58	1.80	0.54	4.30	0.84	-	-	-	-	-	-
SU2	0.80	0.26	1.50	0.43	-	-	-	-	-	-	-	-
CO1	1.60	0.49	3.00	0.88	-	-	-	-	-	-	-	-
CO2	1.50	0.48	2.00	0.58	3.60	0.74	<0.50	0.74	-	-	-	-
AS1	2.90	0.88	1.00	0.30	-	-	-	-	2.20	0.63	-	-
LI	0.40	0.11	-	-	1.40	0.29	-	-	-	-	-	-
UI	-	-	-	-	1.60	0.30	-	-	-	-	<0.20	0.05
HP	0.90	0.27	2.30	0.66	4.20	0.80	0.80	0.20	-	-	-	-

\- NO DATA

Table 4. Mercury (ppm dry weight and wet weight) in fish collected in 1986 from the Sudbury, Concord and Assabet Rivers in Sudbury and Wayland Massachusetts.

STATION	YELLOW PERCH		WHITE PERCH		BROWN BULLHEAD		BLACK CRAPPIE		WHITE SUCKER		CHAIN PICKEREL	
	DW	WW	DW	WW	DW	WW	DW	WW	DW	WW	DW	WW
SU1	1.10	0.37	1.40	0.42	1.05	0.20	-	-	-	-	-	-
SU2	1.05	0.34	1.50	0.43	-	-	-	-	-	-	-	-
CO1	0.75	0.23	1.20	0.35	-	-	-	-	-	-	-	-
CO2	0.95	0.30	1.40	0.40	0.84	0.17	1.70	0.46	-	-	-	-
AS1	0.59	0.17	0.76	0.23	-	-	-	-	1.60	0.46	-	-
LI	0.35	0.09	-	-	0.25	0.05	-	-	-	-	-	-
UI	-	-	-	-	0.69	0.12	-	-	-	-	0.63	0.16
HP	0.35	0.11	1.10	0.31	0.47	0.09	1.80	0.12	-	-	-	-

- NO DATA

Table 5. Arsenic (ppm dry weight and wet weight) in fish collected in 1986 from the Sudbury, Concord, and Assabet Rivers in Sudbury and Wayland, Massachusetts.

STATION	YELLOW PERCH		WHITE PERCH		BROWN BULLHEAD		BLACK CRAPPIE		WHITE SUCKER		CHAIN PICKEREL	
	DW	WW	DW	WW	DW	WW	DW	WW	DW	WW	DW	WW
SU1	0.10	0.03	0.10	0.03	0.10	0.02	-	-	-	-	-	-
SU2	0.10	0.03	0.20	0.06	-	-	-	-	-	-	-	-
CO1	0.20	0.06	0.20	0.06	-	-	-	-	-	-	-	-
CO2	0.20	0.06	0.32	0.09	0.39	0.08	0.31	0.08	-	-	-	-
AS1	0.20	0.06	0.30	0.09	-	-	-	-	-	-	-	-
LI	<0.10	<0.03	-	-	<0.10	<0.02	-	-	-	-	-	-
UI	-	-	-	-	0.10	<0.02	-	-	-	-	<0.1	<0.03
HP	0.20	0.06	0.37	0.11	0.69	0.13	0.30	0.07	-	-	-	-

- NO DATA

Table 6. Contaminants in sediments (ppm dry weight and wet weight) collected in 1987 from the Sudbury and Concord Rivers in Sudbury and Wayland, Massachusetts.

	PAH		PCB		Hg	As	Pb	Cd	Cr
STATION	WW	DW	WW	DW	DW	DW	DW	DW	DW
SU1	0.33	5.89	ND	ND	0.35	10.00	130.00	2.00	29.00
SU2	1.18	7.28	ND	ND	16.40	20.00	190.00	14.00	242.00
SU3	2.70	9.00	0.33	1.10	2.04	<8.00	280.00	6.50	85.00
SU4	0.53	2.47	0.28	1.31	1.40	10.00	150.00	4.90	39.00
SU6	2.59	12.45	ND	ND	0.84	10.00	290.00	4.10	53.00
SU7	1.27	6.55	ND	ND	1.10	<7.00	96.00	4.50	41.00
SU8	0.38	1.79	0.19	0.90	1.40	9.00	110.00	5.20	47.00
SU9	0.15	0.97	ND	ND	0.90	20.00	75.00	3.90	28.00
SU10	0.67	4.24	0.18	1.14	1.94	20.00	160.00	6.10	56.00
SU11	0.86	3.28	ND	ND	1.20	<7.00	110.00	3.90	38.00
SU12	0.81	7.23	ND	ND	1.50	20.00	190.00	3.60	214.00
SU13	0.94	5.91	ND	ND	1.67	10.00	160.00	3.30	188.00
SU14	0.31	4.19	ND	ND	1.40	20.00	210.00	3.10	149.00
WB1	0.26	1.30	ND	ND	0.14	<8.00	56.00	1.20	19.00
WB2	0.51	2.11	ND	ND	0.15	30.00	140.00	0.84	42.00
RAY	88.26	166.53	9.50	17.92	1.30	35.00	360.00	7.10	552.00
LF	1.57	5.57	ND	ND	0.21	40.00	220.00	1.30	28.00

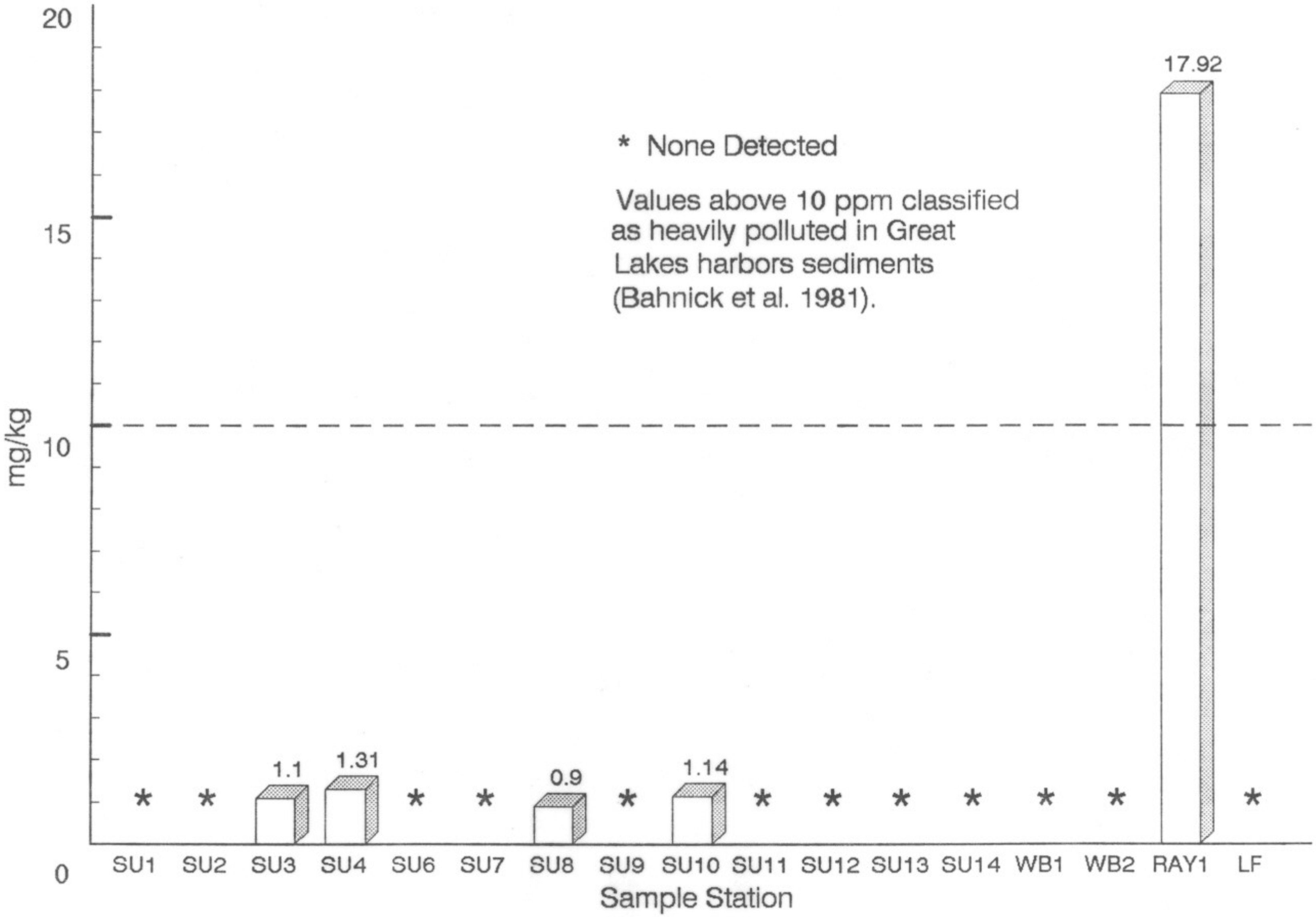


Fig. 7. Total PCB levels in sediments (ppm DW) collected from the Sudbury River in 1987.

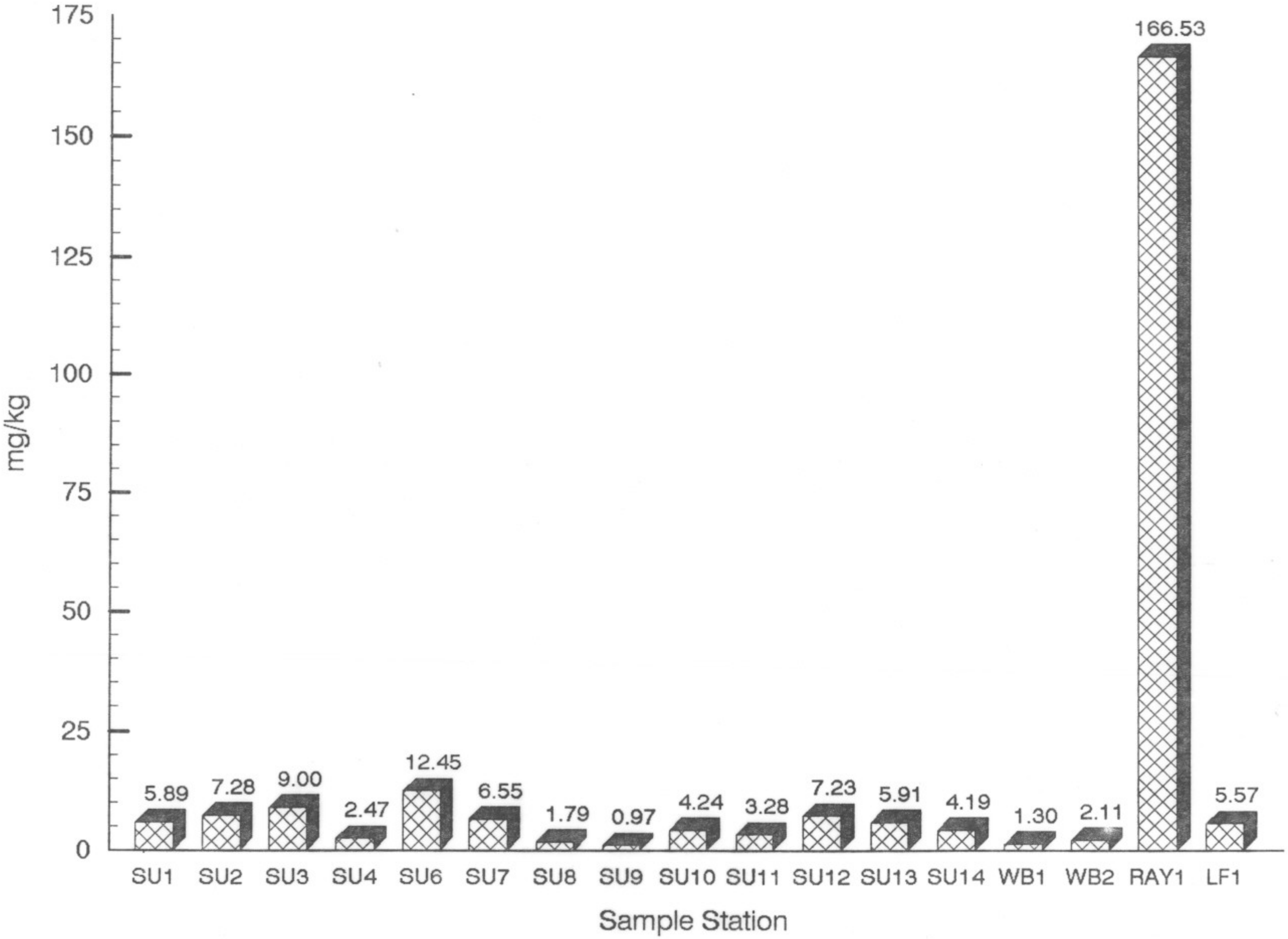


Fig. 8. Total PAH levels in sediments (ppm DW) collected from the Sudbury River in 1987.

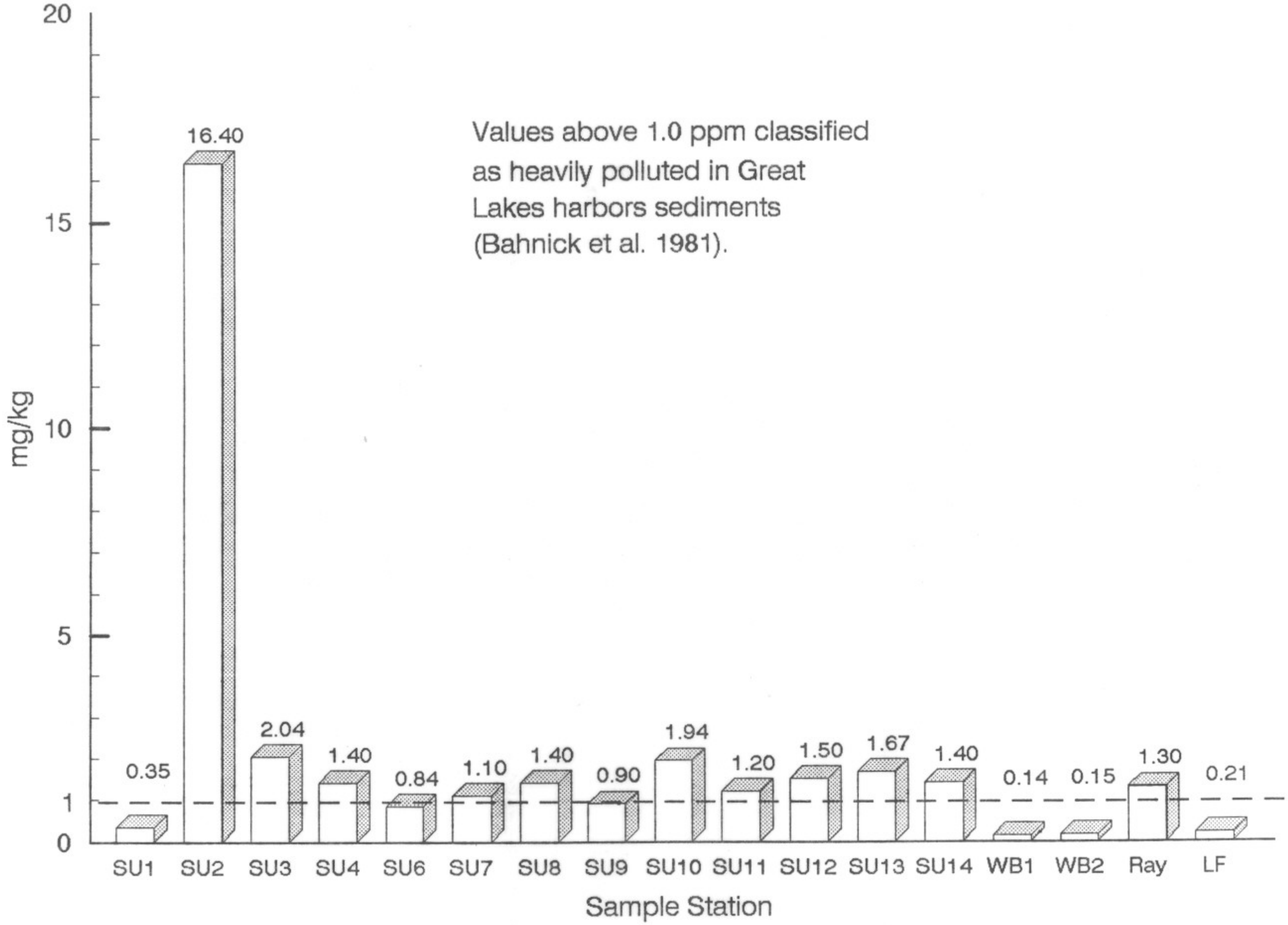


Fig. 9. Mercury levels in sediments (ppm DW) collected from the Sudbury River in 1987.

Arsenic was detected at all stations, and 13 of the 17 sampling locations exceeded Bahnick et al.'s 8.0 ppm threshold for heavily polluted sediments. The highest arsenic levels were found at WB2, RAY1 and LF1, with levels of 30.0, 35.0, and 40.0 ppm, respectively. The lowest concentrations were found at stations SU7 and SU11 with levels of 7.0 ppm (Fig. 10).

Lead levels exceeded the Bahnick et al.'s 60.0 ppm threshold for heavily polluted sediments at all stations except WB1, which had a concentration of 56.0 ppm. Levels at the other stations ranged from 75.0 ppm at SU9 to 360.0 ppm at RAY1 (Fig. 11).

Cadmium levels exceeded Bahnick et al.'s 6.0 ppm threshold for unpolluted sediments at 4 of the 17 stations. The levels at stations SU2, RAY1, SU3, and SU10 were 14.0, 7.1, 6.5, and 6.1 ppm, respectively. Levels at the remaining stations ranged from 0.8 ppm at WB2 to 4.9 ppm at SU4 (Fig. 12).

Chromium was detected in highest concentration (552.0 ppm) at station Ray1. Chromium levels also exceeded Bahnick et al.'s threshold for heavily polluted sediments, (75 ppm), at five other stations. Levels at stations SU2, SU12, SU13, SU14, and SU3 were 242.0, 214.0, 188.0, 149.0, and 85.00 ppm, respectively. Other stations ranged from 19.00 to 85.00 ppm with the lowest concentrations being found at station WB1 (Fig. 13).

Fish

Organic Compounds:

PCBs were detected in **wholebody** fish at concentrations at, or above, the 2.0 ppm FDA action level (**edible portion**) at 10 out of 13 stations. No PCBs were detected in fish at station SU1 (Table 7). PCBs appear to have been more concentrated in yellow perch and white perch, while black crappie appear to have bioaccumulated PCBs in lesser amounts (Fig. 14).

Wholebody dieldrin levels exceeded the 0.30 ppm FDA action level (edible portion) in yellow perch at station SU4. Dieldrin was not detected at stations SU1 and SU2. Levels at the other stations ranged from 0.01 to 0.19 ppm (Table). Levels of dieldrin were consistently higher in yellow perch than in white perch or black crappie (Fig. 15).

Total DDT was detected in all fish samples, but levels were relatively low, ranging from 0.06 to 0.63 ppm (Table 9). Other organochlorine pesticides were not detected in notable concentrations (Append. 3).

PAHs were not found in fish flesh in significant concentrations at any stations (Table 10).

Metals:

Wholebody lead was found to be elevated above the 1.0 ppm FDA action level for the edible portion of fish at one station (SU3), where the concentration in white perch was 1.08 ppm. Wholebody lead concentrations at the other stations ranged from 0.12 to 0.52 ppm, with no apparent trends within species (Table 11; Fig. 16).

Fish tissue levels of mercury were not found to be elevated at any of the stations. Values ranged from 0.09 to 0.63 ppm (Table 12; Fig. 17).
Other metals were not found at notable levels (Append. 5).

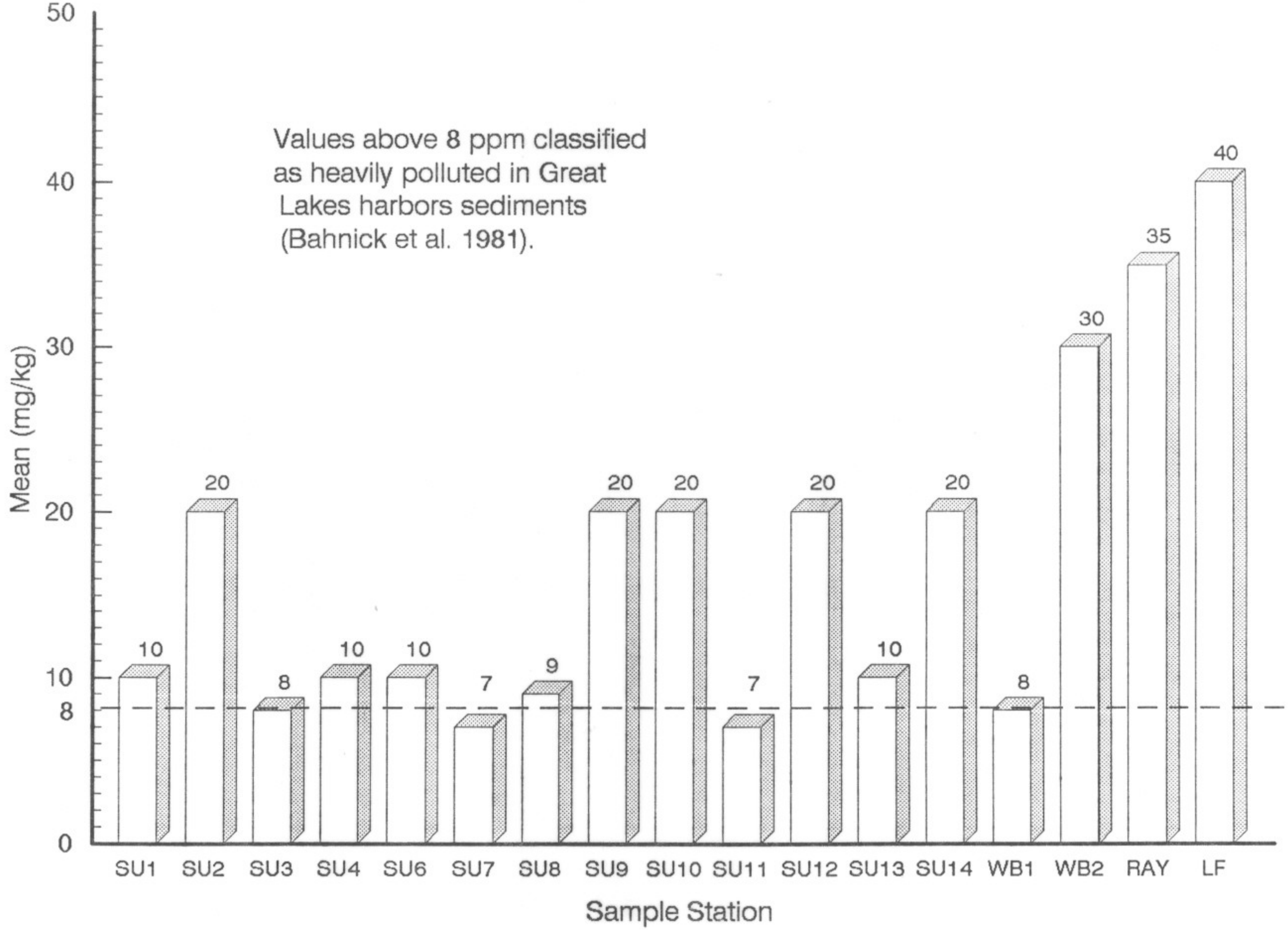


Fig. 10. Arsenic in sediments (ppm DW) collected from the Sudbury River in 1987.

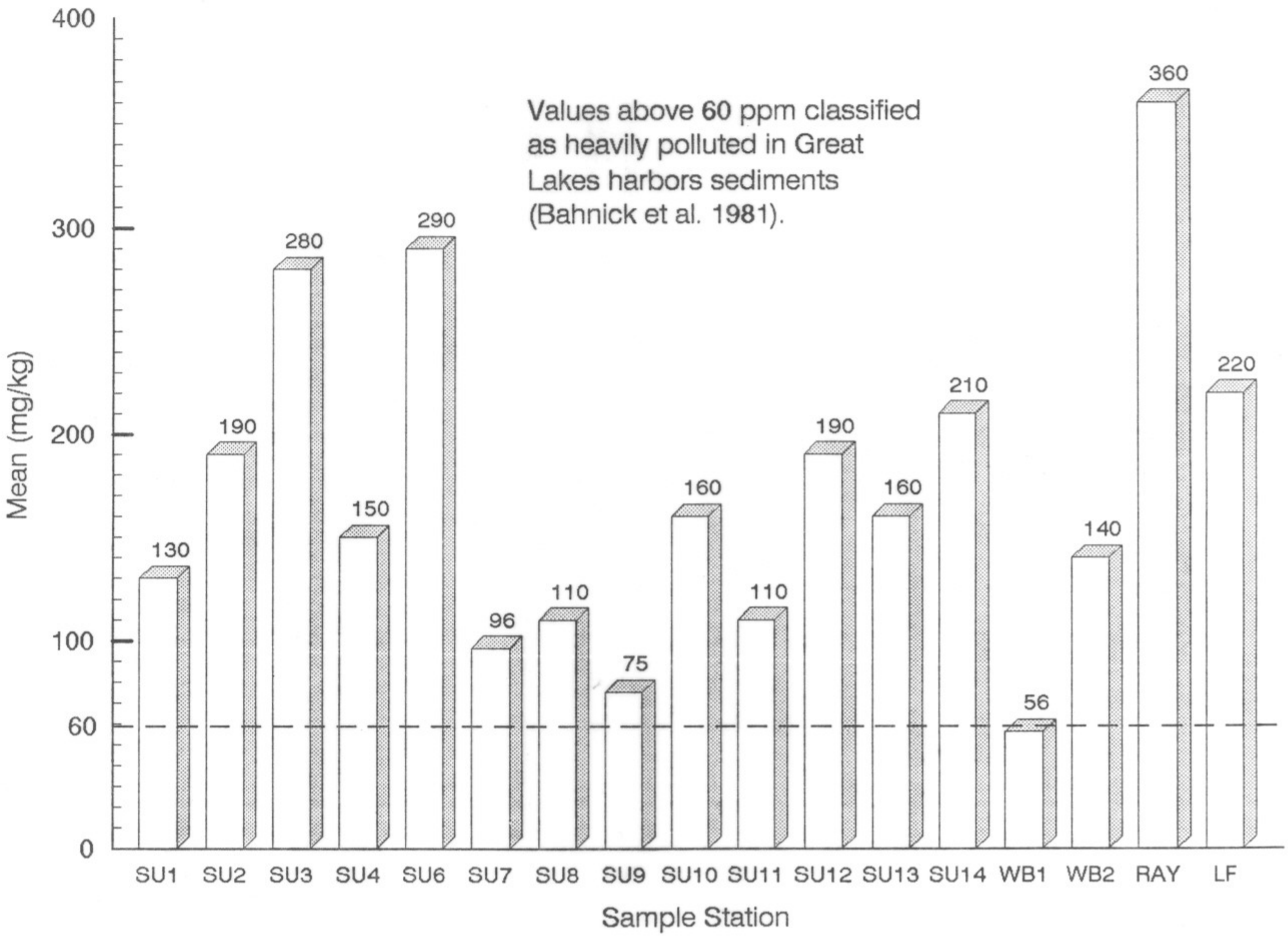


Fig. 11. Lead in sediments (ppm DW) collected from the Sudbury River in 1987.

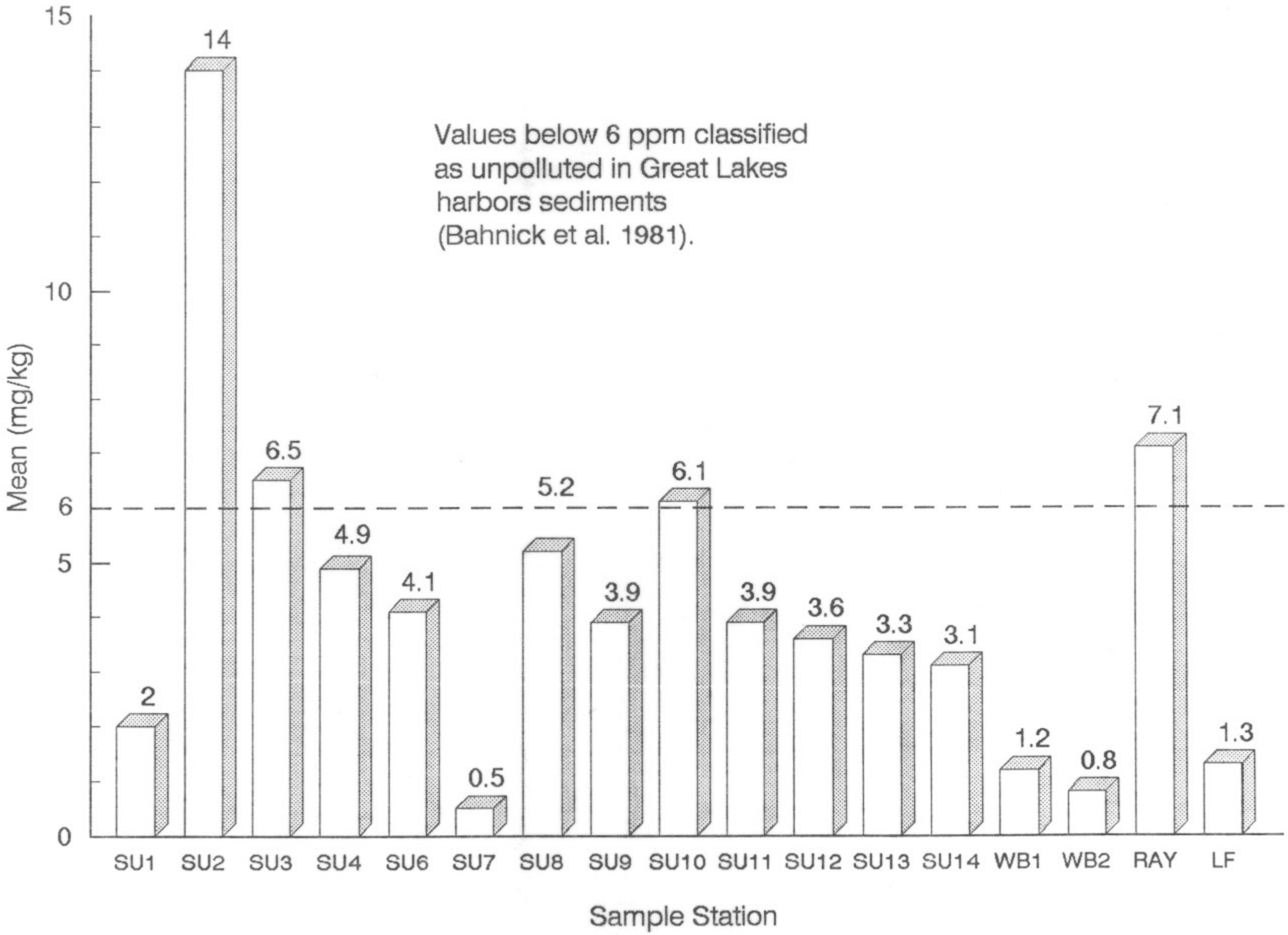


Fig. 12. Cadmium in sediments (ppm DW) collected from the Sudbury River in 1987.

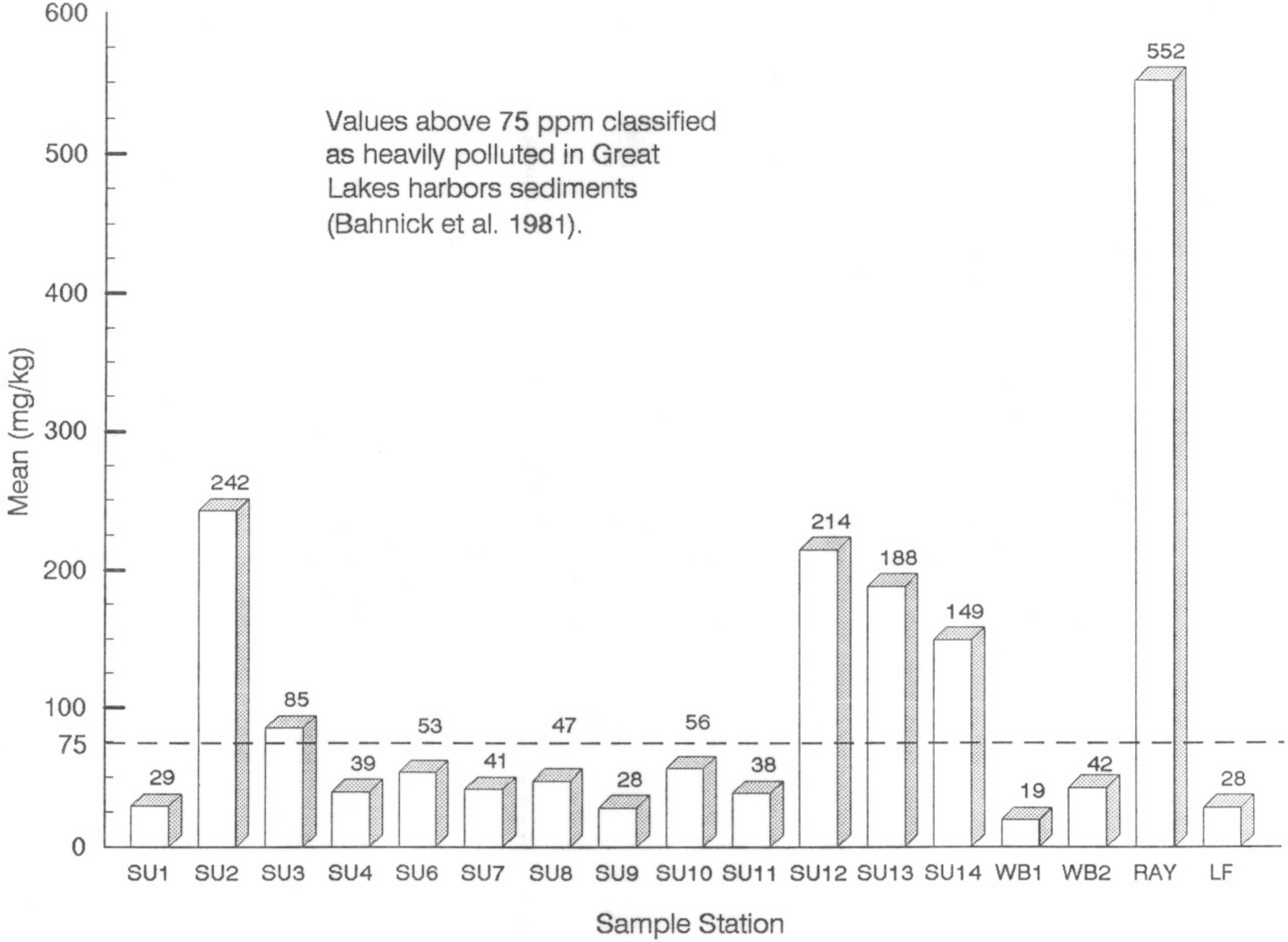


Fig. 13. Chromium in sediments (ppm DW) collected from the Sudbury River in 1987.

Table 7. Total PCBs (ppm wet weight) in fish collected in 1987 from the Sudbury River, Sudbury and Wayland, Massachusetts.

STATION	YELLOW PERCH	WHITE PERCH	BLACK CRAPPIE
SU1	ND	-	ND
SU2	0.48	0.77	-
SU3	2.10*	3.50*	-
SU4	4.20*	2.40*	1.70
SU5	3.05*	3.10*	-
SU6	3.00*	-	1.50
SU7	2.40*	2.20*	-
SU8	2.00*	1.90*	-
SU9	2.00*	2.10*	-
SU10	1.90*	2.40*	1.10
SU11	2.00*	-	0.55
SU12	0.95	2.90*	-
SU13	1.10	1.20	-

- No Data
* Exceeds FDA action level (2.0 ppm) for edible portion of fish samples are whole fish

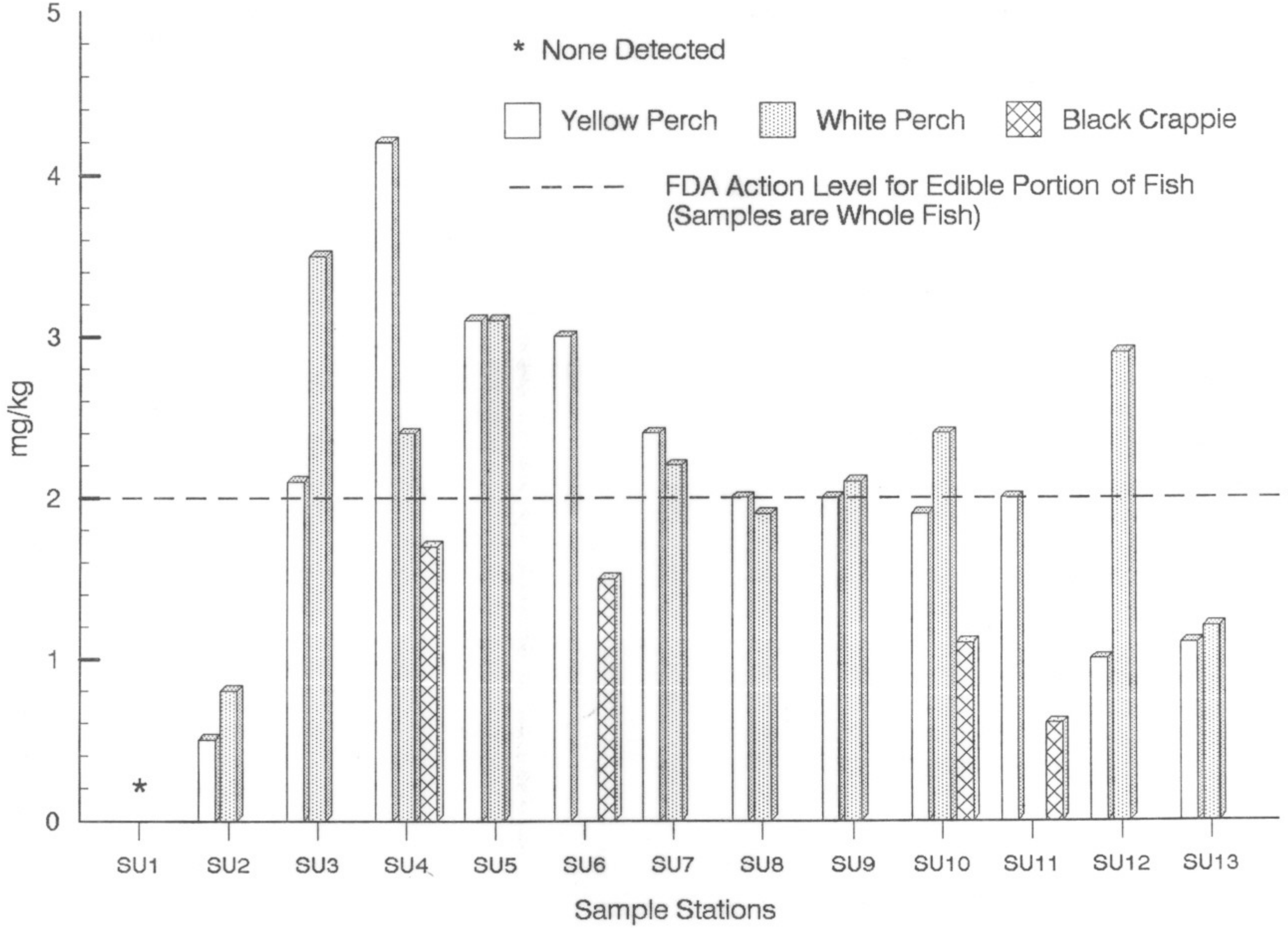


Fig. 14. Total PCB levels in fish (ppm WW) collected from the Sudbury River in 1987.

Table 8. Dieldrin (ppm wet weight) in fish collected in 1987 from the Sudbury River, Sudbury and Wayland, Massachusetts.

STATION	YELLOW PERCH	WHITE PERCH	BLACK CRAPPIE
SU1	ND	-	ND
SU2	ND	ND	-
SU3	0.15	0.07	-
SU4	0.32*	0.08	0.07
SU5	0.19	0.09	-
SU6	0.23	-	0.08
SU7	0.15	0.09	-
SU8	0.14	0.05	-
SU9	0.11	0.04	-
SU10	0.11	0.07	0.03
SU11	0.09	-	0.01
SU12	0.05	0.05	-
SU13	0.07	0.03	-

- No Data
ND - None Detected
* Exceeds FDA action level (0.30 ppm) for edible portion of fish.
  Samples are whole fish.

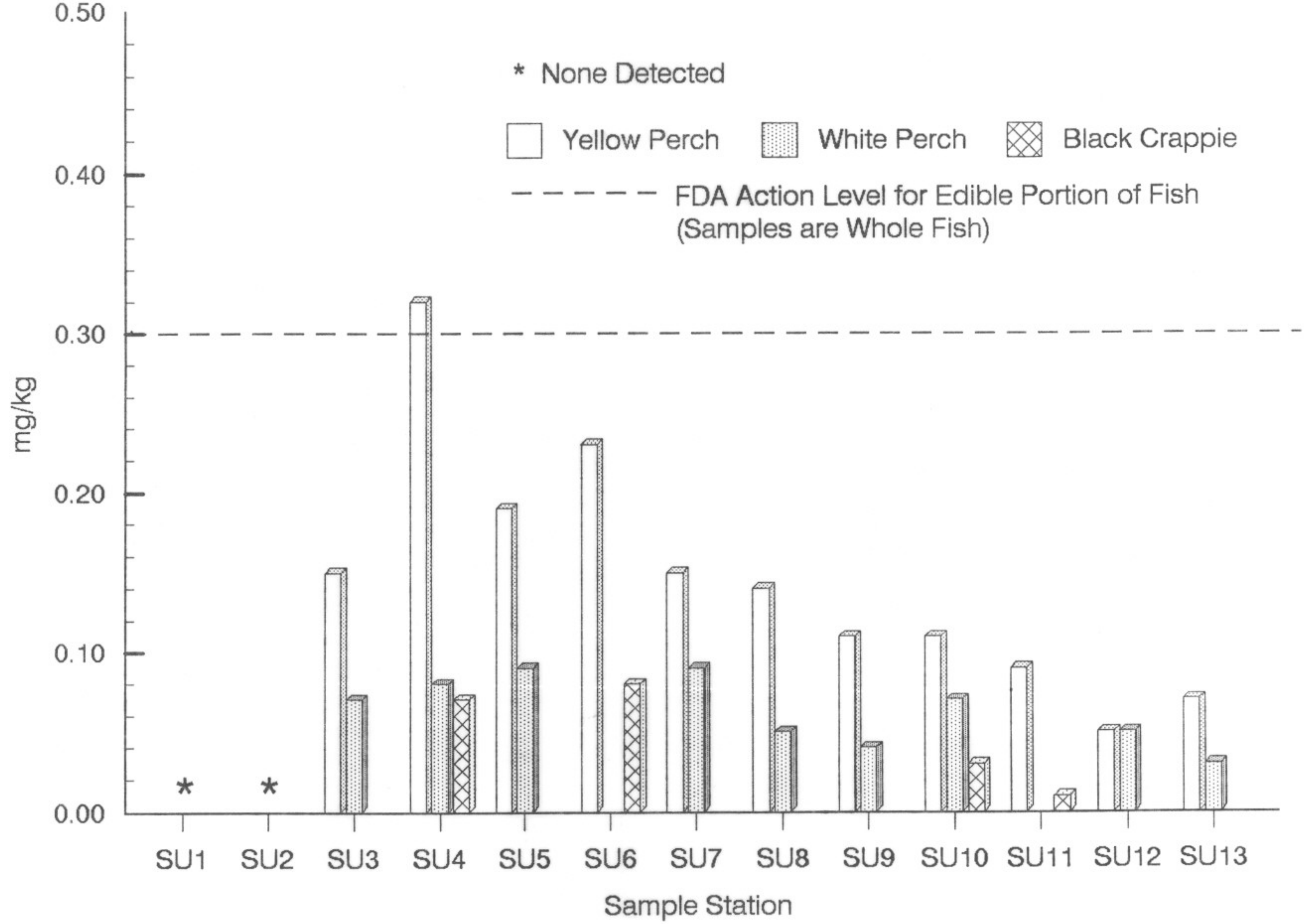


Fig. 15. Dieldrin levels in fish (ppm WW) collected from the Sudbury River in 1987.

Table 9. Total DDT levels (ppm wet weight) in fish collected in 1987 from the Sudbury River, Sudbury and Wayland, Massachusetts.

STATION	YELLOW PERCH	WHITE PERCH	BLACK CRAPPIE
SU1	0.07	-	0.06
SU2	0.22	0.30	-
SU3	0.43	0.41	-
SU4	0.45	0.27	0.18
SU5	0.35	0.39	-
SU6	0.34	-	0.15
SU7	0.29	0.63	-
SU8	0.59	0.57	-
SU9	0.34	0.35	-
SU10	0.33	0.32	0.17
SU11	0.27	-	0.06
SU12	0.28	0.54	-
SU13	0.30	0.29	-

- NO DATA

TABLE 10. PAHs (ppm wet weight) in fish collected in 1987 from the Sudbury River, Sudbury and Wayland, Massachusetts.

STATION	YELLOW PERCH	WHITE PERCH	BLACK CRAPPIE
SU1	0.04	-	0.03
SU2	0.02	0.01	-
SU3	0.02	0.04	-
SU4	0.04	0.02	0.01
SU5	0.04	0.03	-
SU6	0.12	-	0.02
SU7	0.19	0.01	-
SU8	0.05	0.02	-
SU9	0.02	0.02	-
SU10	0.02	0.03	0.02
SU11	0.05	-	0.01
SU12	0.03	0.02	-
SU13	0.04	0.02	-

- NO DATA

Table 11. Lead (ppm dry weight and wet weight) in fish collected in 1987 from the Sudbury River, Sudbury and Wayland, Massachusetts.

STATION	YELLOW PERCH		WHITE PERCH		BLACK CRAPPIE	
	DW	WW	DW	WW	DW	WW
SU1	0.50	0.15	-	-	0.50	0.19
SU2	0.50	0.13	0.50	0.12	-	-
SU3	1.60	0.48	4.10	1.08	-	-
SU4	1.80	0.52	0.50	0.14	0.90	0.23
SU5	0.89	0.30	0.50	0.15	-	-
SU6	0.80	0.26	-	-	0.70	0.19
SU7	0.80	0.24	2.00	0.49	-	-
SU8	1.00	0.31	0.50	0.14	-	-
SU9	0.50	0.14	2.00	0.43	-	-
SU10	0.80	0.24	1.50	0.34	0.50	0.13
SU11	1.00	0.32	-	-	2.10	0.52
SU12	0.80	0.25	0.50	0.15	-	-
SU13	1.00	0.32	1.70	0.43	-	-

- NO DATA

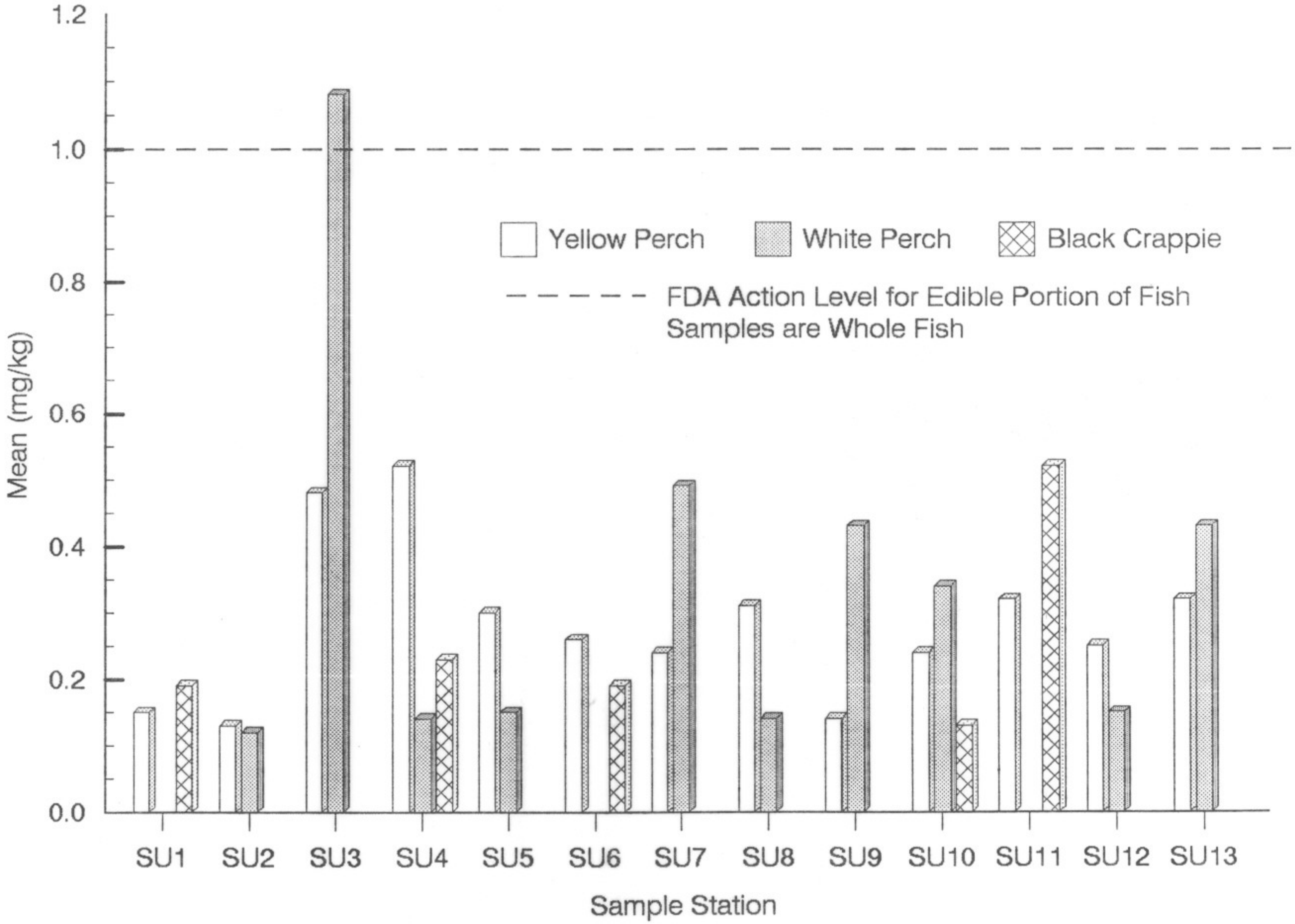


Fig. 16. Lead levels in fish (ppm WW) collected from the Sudbury River in 1987.

Table 12. Mercury (ppm dry weight and wet weight) in fish collected in 1987 from the Sudbury River, Sudbury and Wayland, Massachusetts.

STATION	YELLOW PERCH		WHITE PERCH		BLACK CRAPPIE	
	DW	WW	DW	WW	DW	WW
SU1	0.30	0.09	-	-	0.30	0.11
SU2	1.90	0.50	2.90	0.25	-	-
SU3	0.88	0.26	1.20	0.32	-	-
SU4	0.91	0.26	1.50	0.41	1.70	0.43
SU5	0.91	0.30	1.30	0.39	-	-
SU6	1.10	0.36	-	-	1.40	0.39
SU7	1.20	0.36	2.30	0.56	-	-
SU8	1.01	0.31	2.00	0.56	-	-
SU9	1.02	0.29	2.40	0.52	-	-
SU10	0.95	0.29	2.20	0.58	2.50	0.63
SU11	0.89	0.28	-	-	2.10	0.52
SU12	0.55	0.17	1.40	0.41	-	-
SU13	0.70	0.23	1.30	0.33	-	-

- NO DATA

Hg
(0.09–0.63)
0.09 – ppm ww
" dw

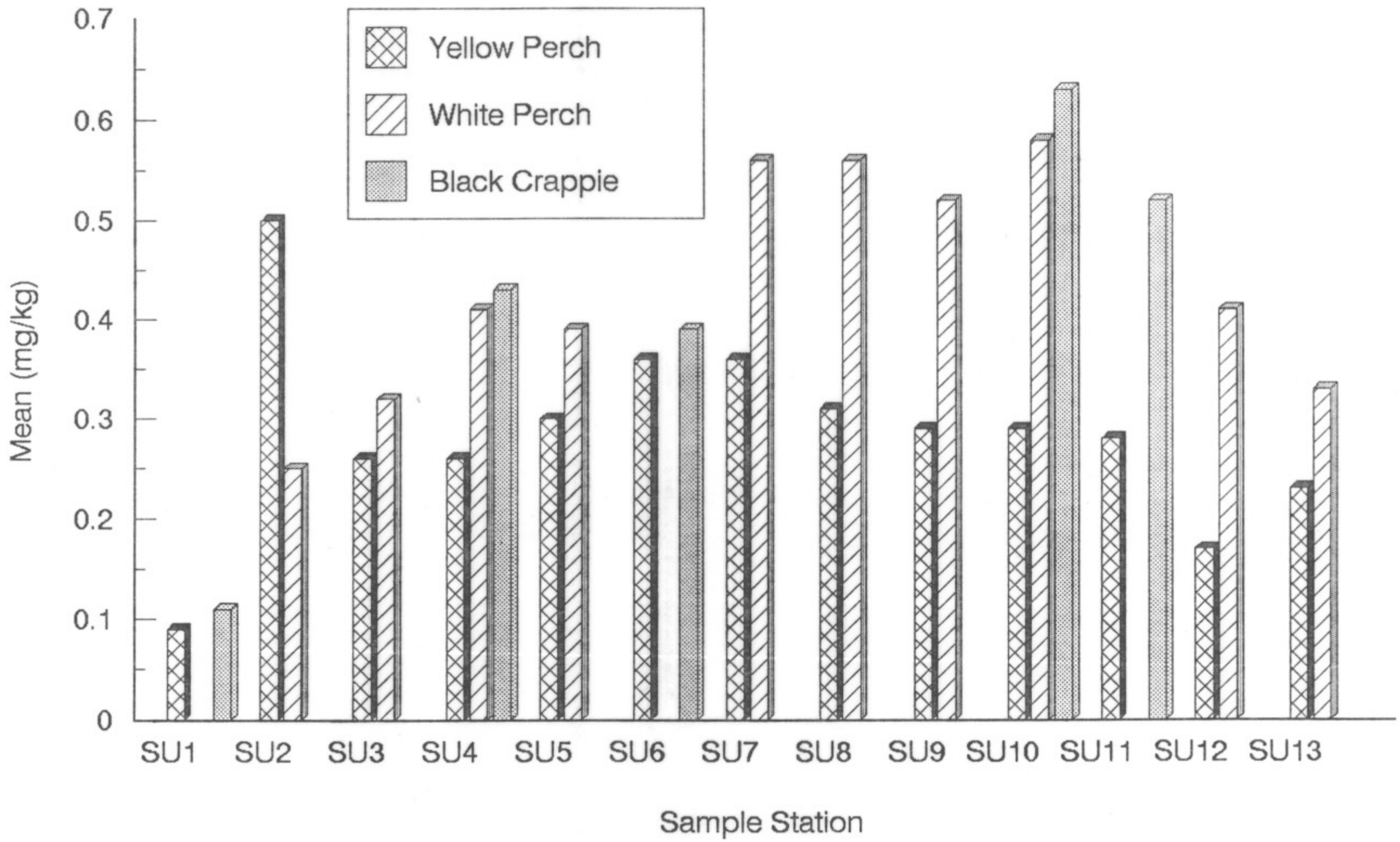


Fig. 17. Mercury levels in fish (ppm WW) collected from the Sudbury River in 1987.

Red-winged Blackbird Eggs

Table 13 displays the results of the analyses of the red-winged black bird egg composite samples for PCBs and organochlorine pesticides. Total PCBs were present in eggs at all four sample stations in significant amounts, ranging from 1.50 to 6.00 ppm. Figure 18 suggests that PCBs, DDE and dieldrin were found in the greatest amounts at the same locations. DDE concentrations ranged from 0.23 to 1.00 ppm, and dieldrin concentrations ranged from 0.02 to 0.45 ppm. Other pesticides and PAHs were not found to be present in notable amounts (Append. 3 and 4).

Small Mammals

Table 14 displays contaminant levels found in the small mammal samples. No contaminants were found at exceptional concentrations. However, levels of chromium were notably higher at WB1 and at SU7 relative to the other stations sampled, as were levels of lead at stations LF1 and WB1.

1989 Sampling

Contaminant concentrations in the sediment samples are reported in table 15.

Sediment

Organic Compounds:

In this "hotspot" survey, sediment PCB concentrations were "very high" at six of the 14 stations. Levels at these stations ranged from 30.4 to 117.00 ppm (GMS 1-5, and GMS 9). Sediment PCB levels at the remaining stations ranged from 0.54 to 3.21 ppm (Fig. 19). The list of PCBs analyzed for are provided in appendix 6.

Total PAHs were significantly elevated at the same six stations that had the highest PCBs. The concentrations of total PAHs at these six locations ranged from 30.40 to 1004.00 ppm, with the highest concentrations at GMS 4, 3, and 5. Levels at the remaining stations ranged from 1.67 to 10.9 ppm (Fig. 20). The list of PAHs analyzed for are provided in appendix 8.

Dieldrin and other organochlorine pesticides were not detected at the 1989 sediment sampling stations (Append. 6 and 7). Although aliphatic hydrocarbons were detected in low amounts at all stations, they were notably higher at GMS 2 and 3 (Append. 8).

Metals:

Mercury was detected at all sampling stations, with the highest concentrations at GMS 3, 8, 13, and 14 (4.6, 3.5, 3.1, and 3.2 ppm, respectively). Figure 21 suggests that the areas of greatest sediment mercury concentration were in the floodplain wetlands, and the least were in the mainstem of the river.

Table 13. Total PCB, DDE and dieldrin levels (ppm wet weight) in red-winged blackbird eggs collected from wetlands adjacent to the Sudbury River, Sudbury and Wayland, Massachusetts.

STATION	PCB	DIELDREN	DDE
RAY1	6.00	0.45	0.93
SU7	1.50	0.07	0.23
SU11	3.30	0.10	1.00
SU14	2.00	0.02	0.51

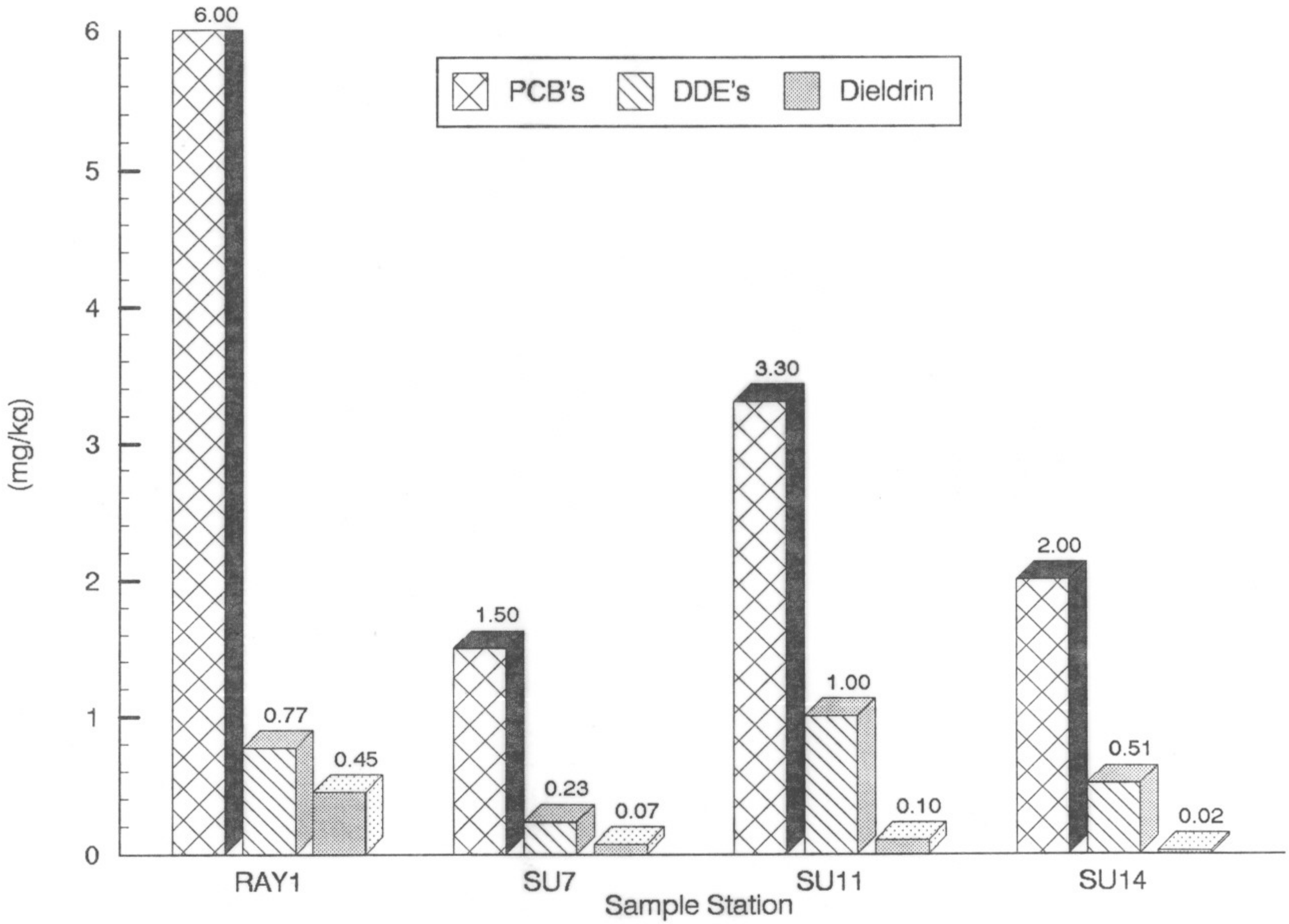


Fig. 18. Total PCB, DDE, and dieldrin levels (ppm WW) in red-winged blackbird eggs collected in 1987 from wetlands adjacent to the Sudbury River.

Table 14. Contaminants levels in small mammals (ppm) captured in 1987 adjacent to the Sudbury River, Sudbury and Wayland, Massachusetts.

STATION	MERCURY		CADMIUM		CHROMIUM		LEAD		TOTAL PCB	TOTAL DDE	DIELDRIN
	DW	WW	DW	WW	DW	WW	DW	WW	WW	WW	WW
SU7-MICROTUS	0.12	0.04	0.10	0.03	201.00	67.13	1.00	0.33	0.07	ND	0.05
SU14-MICROTUS	0.02	0.01	0.17	0.05	2.00	0.53	<0.40	0.11	ND	0.01	ND
ZAPUS	0.03	0.01	0.08	0.03	3.00	0.95	<0.40	0.13	ND	0.01	0.11
LF- ZAPUS	0.13	0.04	0.18	0.28	1.20	0.34	8.30	2.36	ND	ND	ND
RAY- MICROTUS	0.10	0.03	0.31	0.08	11.60	3.00	1.00	0.26	ND	0.01	0.01
ZAPUS	0.03	0.01	0.18	0.32	2.80	0.89	0.90	0.29	ND	0.01	0.04
WB1- ZAPUS	0.11	0.04	0.75	0.26	262.00	91.44	4.40	1.54	ND	ND	ND
WB2- PEROMYSCUS	0.13	0.04	0.08	0.02	3.20	1.00	1.80	0.55	ND	ND	ND

ND - NONE DETECTED

Table 15. Contaminants in sediments (ppm) collected in 1989 from the Sudbury River and adjacent wetlands in Wayland, Massachusetts.

STATION	TOTAL PAH		TOTAL PCB		Hg	As	Pb	Cd	Cr	Cu
	WW	DW	WW	DW	DW	DW	DW	DW	DW	DW
GMS 1	147.90	236.00	15.00	24.00	0.83	8.40	280.00	3.20	221.00	1470.00
GMS 2	120.00	454.50	25.00	95.00	2.37	10.50	858.00	8.10	1730.00	3120.00
GMS 3	46.80	316.00	6.70	45.00	4.60	12.30	1590.00	16.00	15100.00	9440.00
GMS 4	275.30	1004.70	28.00	102.00	3.00	11.10	734.00	6.50	366.00	1960.00
GMS 5	90.00	584.40	18.00	117.00	2.93	9.40	960.00	8.80	743.00	2360.00
GMS 7	1.11	5.97	0.34	1.80	2.38	22.40	350.00	4.40	100.00	136.00
GMS 8	2.25	10.90	0.58	2.80	3.50	19.60	390.00	6.00	253.00	397.00
GMS 9	6.48	31.80	6.20	30.40	2.19	7.30	260.00	12.00	506.00	1050.00
GMS 10	0.62	2.30	0.24	0.90	1.00	8.10	180.00	4.40	65.00	103.00
GMS 11	0.71	4.90	0.16	1.10	1.52	22.20	280.00	6.00	96.00	185.00
GMS 12	0.34	3.40	0.10	1.00	1.50	14.40	300.00	3.40	68.00	143.00
GMS 13	0.57	3.52	0.52	3.21	3.08	9.10	330.00	4.00	119.00	173.00
GMS 14	0.77	4.05	0.43	2.26	3.21	11.20	270.00	13.00	99.00	160.00
GMS 15	0.28	1.67	0.09	0.54	0.68	15.70	140.00	4.20	58.00	64.80

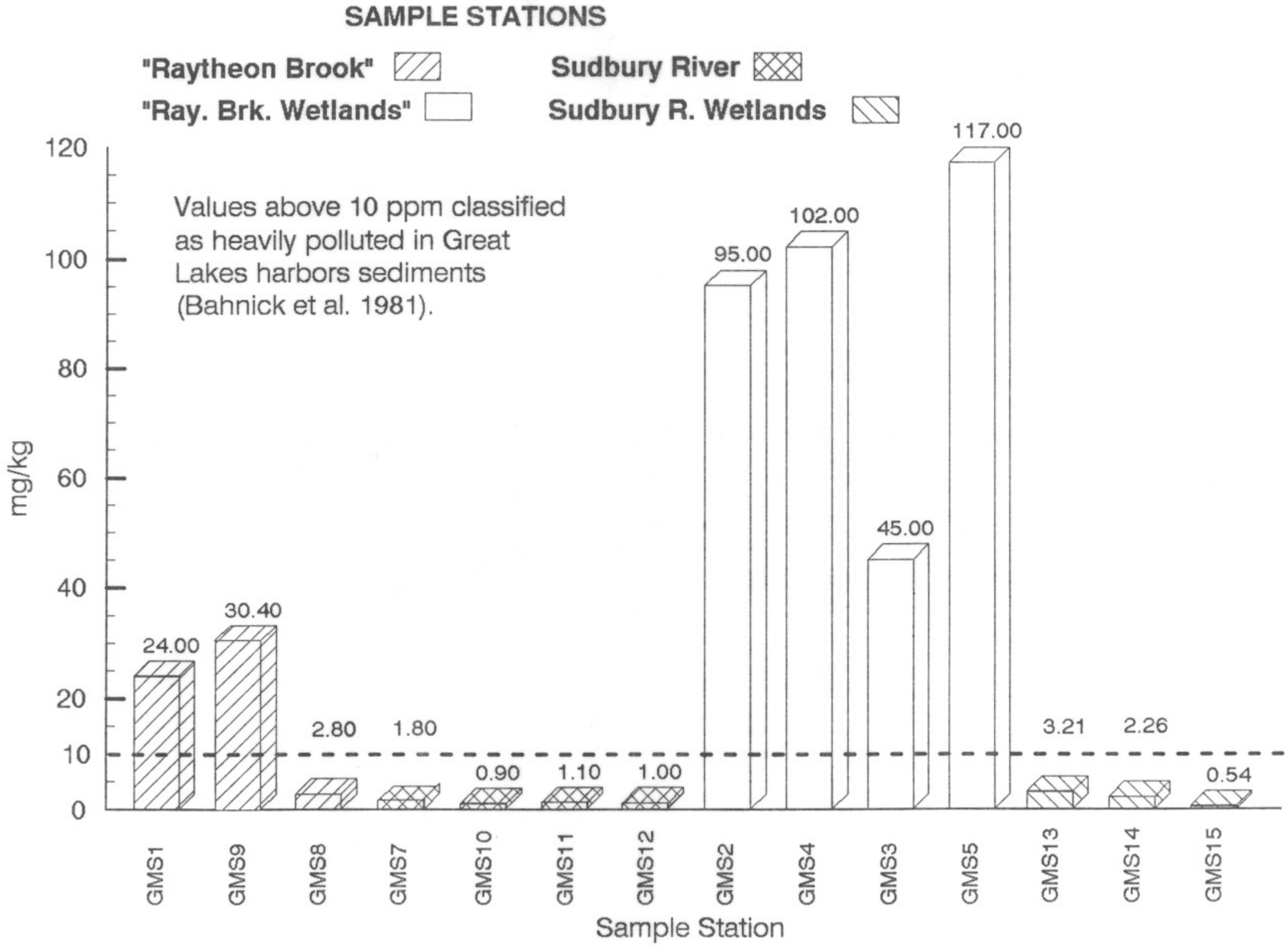


Fig. 19. Total PCBs in sediments (ppm DW) collected from the Sudbury River in 1989.

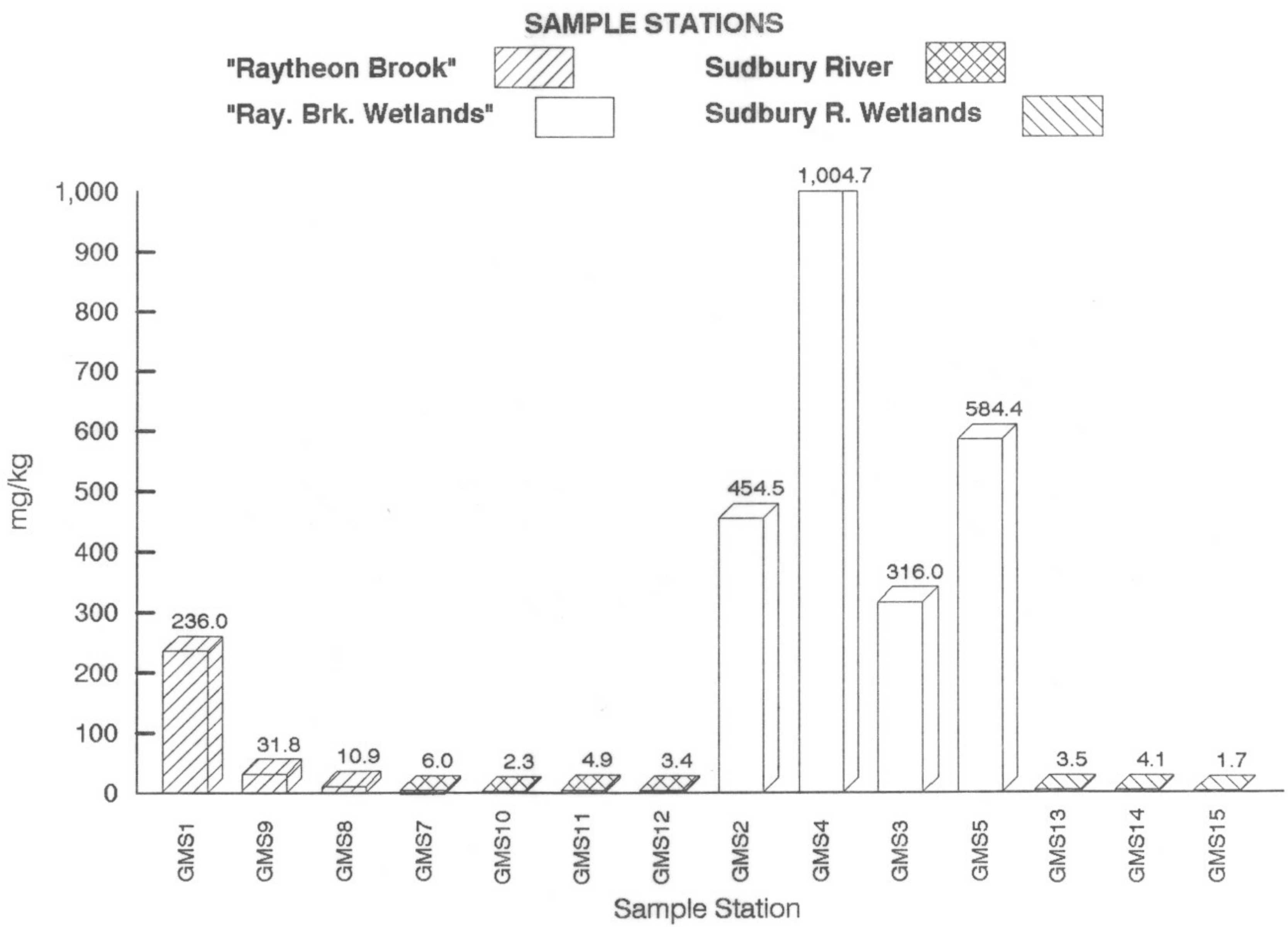


Fig. 20. Total PAHs in sediments (ppm DW) collected from the Sudbury River in 1989.

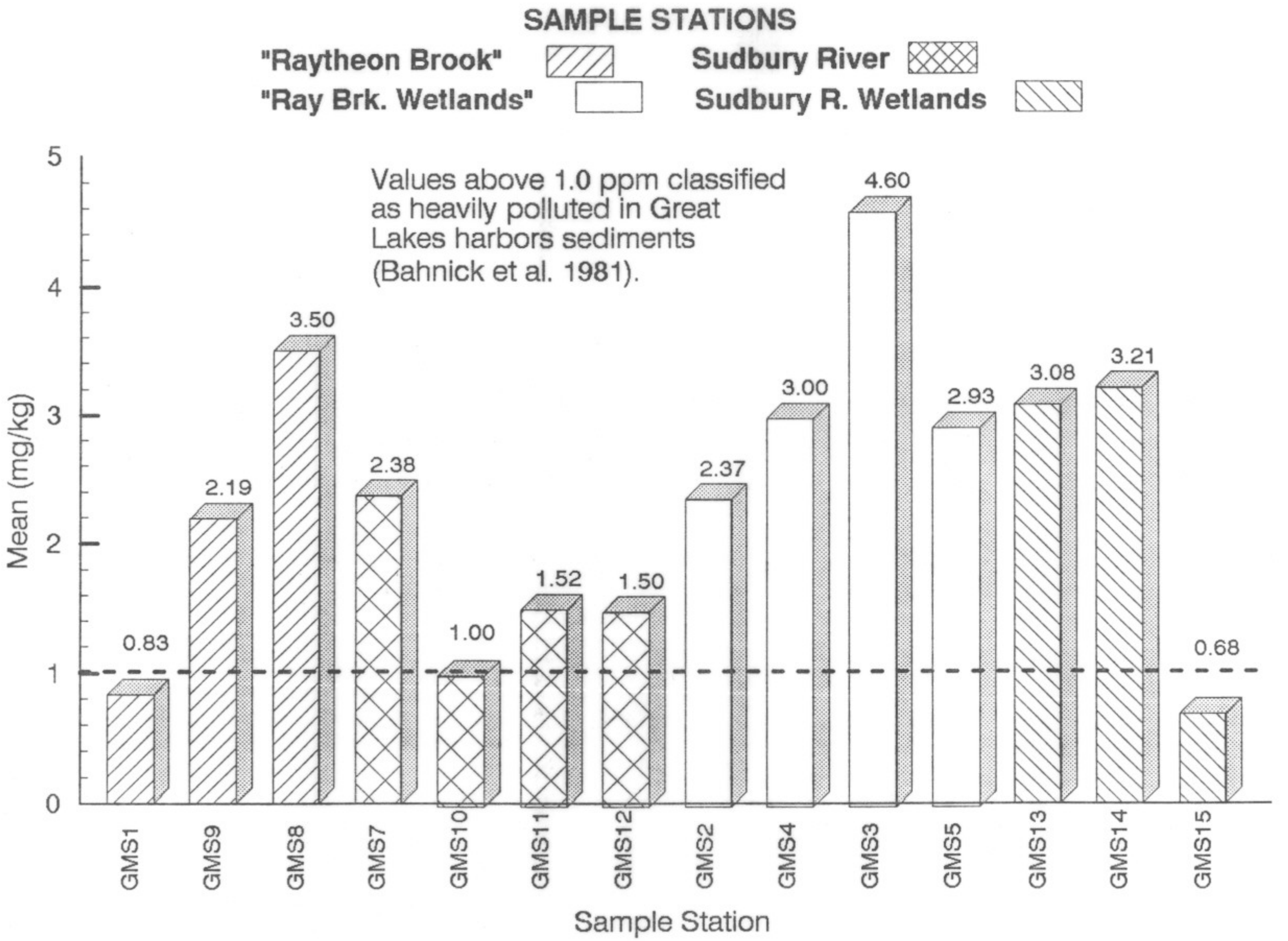


Fig. 21. Mercury in sediments (ppm DW) collected from the Sudbury River in 1989.

Arsenic was detected in the highest concentrations at stations GMS 7, 11, 8, and 15, with levels of 22.4, 22.2, 19.6, and 15.7 ppm, respectively. Concentrations at all but GMS 9 (7.3 ppm) exceed Bahnick _et al._'s 8.0 ppm threshold criterion for heavily polluted sediments. Figure 22 suggests higher concentrations of arsenic along the mainstem of the river than in the floodplain wetlands.

Lead was detected at elevated levels at all sampling stations, however, the concentration at GMS 3 was dramatically the highest. Levels ranged from 140.0 ppm at GMS 15 to 1,590 ppm at GMS 3. Bahnick _et al._ classified sediments with concentrations greater than 40.0 ppm of lead as heavily polluted. Figure 23 indicates that the highest levels were found in the floodplain wetlands near Raytheon Brook.

Cadmium levels exceeded Bahnick _et al._'s 6.0 ppm threshold for unpolluted sediments at five stations. GMS 3 had the highest concentration of 16.0 ppm, followed by GMS 14 with 13.0 ppm, and GMS 9 with 12.0. No clear trend is evident in the distribution of this metal (Fig. 24).

Chromium concentrations at all sampling locations, except GMS 10 and GMS 15, were elevated above Bahnick _et al._'s 75.0 ppm threshold for heavily polluted sediments. GMS 3 had a dramatically high concentration of 15,100 ppm, followed by GMS 2 with a concentration of 1,730 ppm. The other stations ranged from 58.0 ppm to 743 ppm. Figure 25 suggests that the highest levels were in the sediments of the floodplain wetlands near Raytheon Brook.

Levels of all heavy metals detected in the sediments are reported in appendix 9.

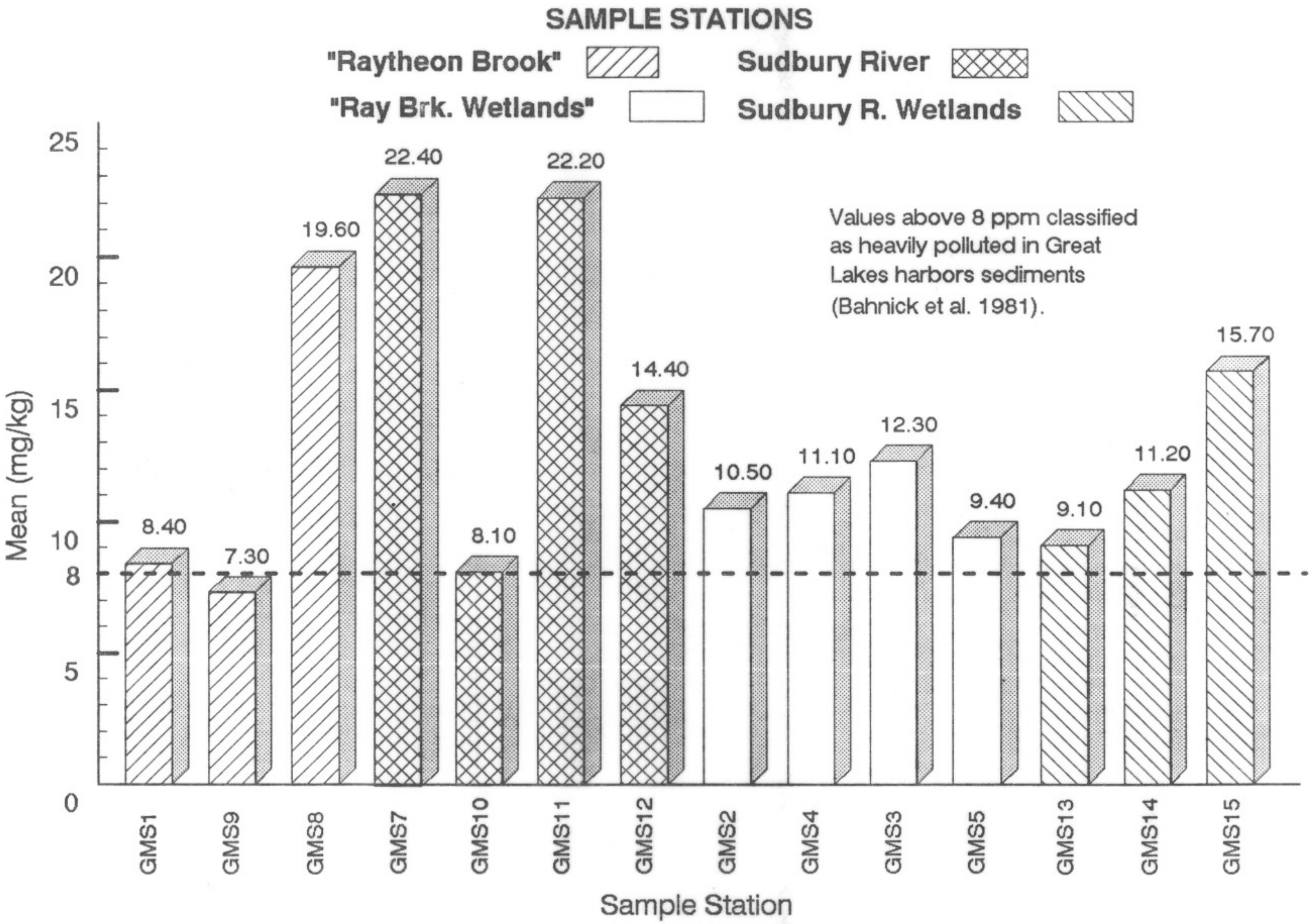


Fig. 22. Arsenic in sediments (ppm DW) collected from the Sudbury River in 1989.

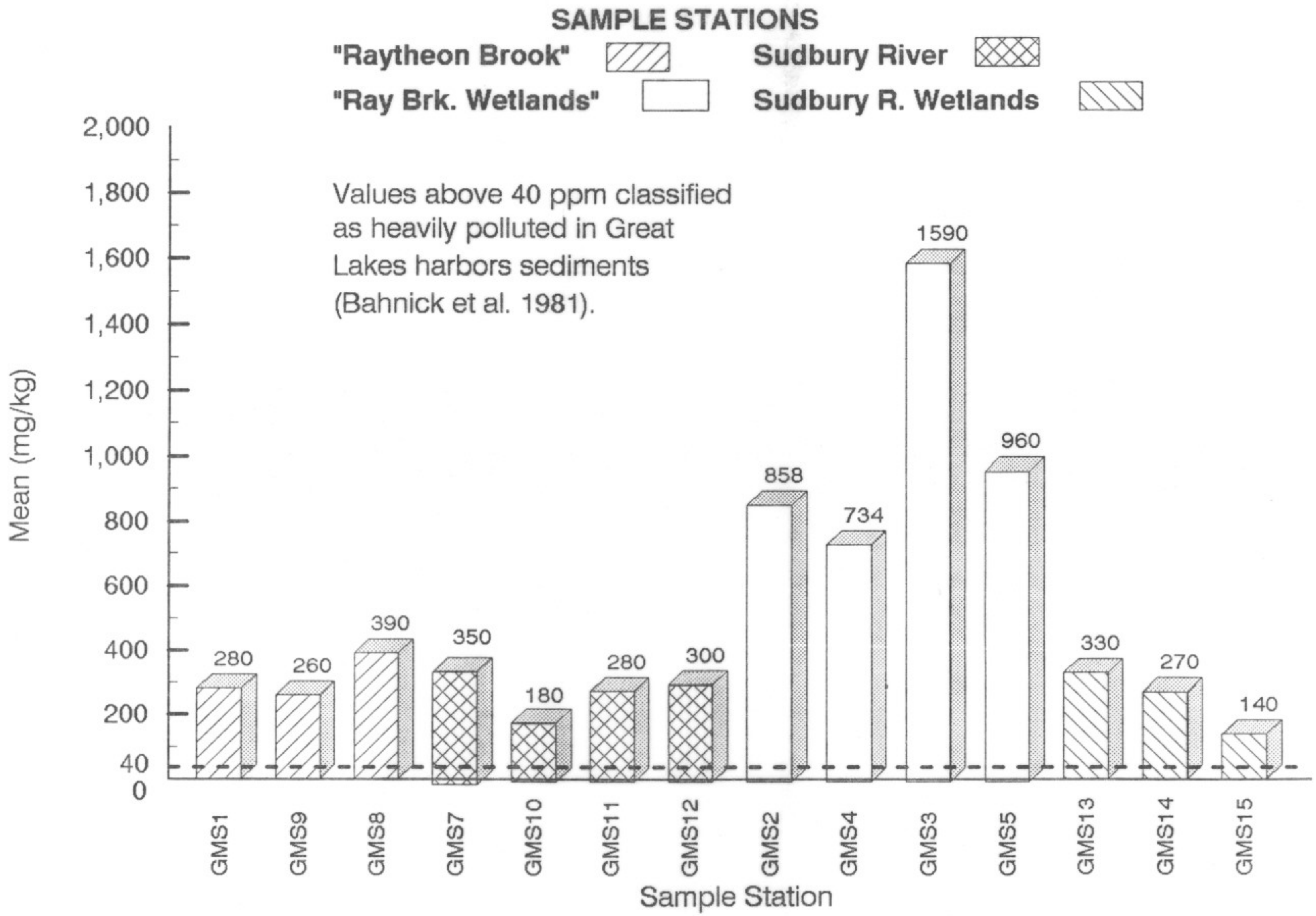


Fig. 23. Lead in sediments (ppm DW) collected from the Sudbury River in 1989.

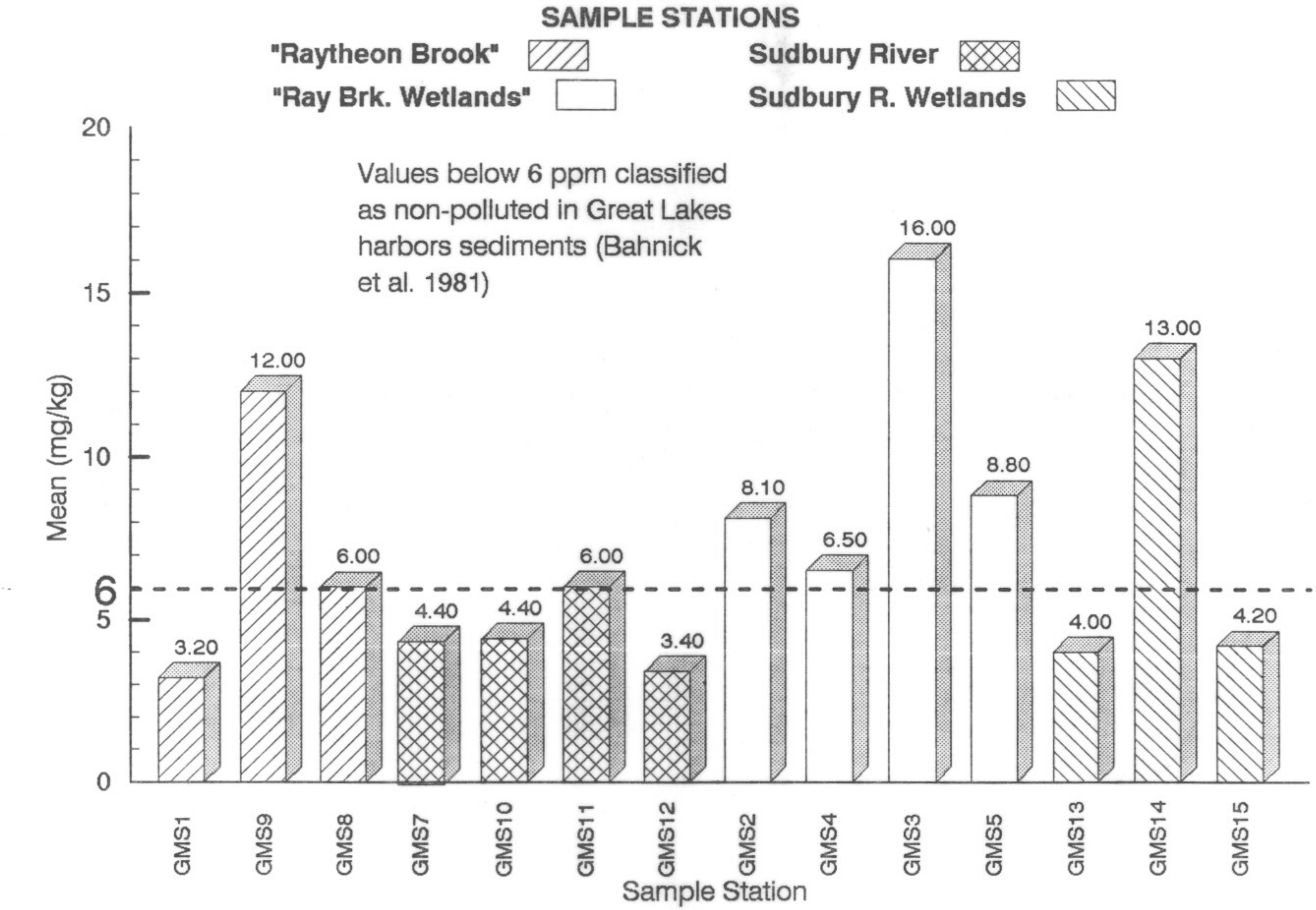


Fig. 24. Cadmium in sediments (ppm DW) collected from the Sudbury River in 1989.

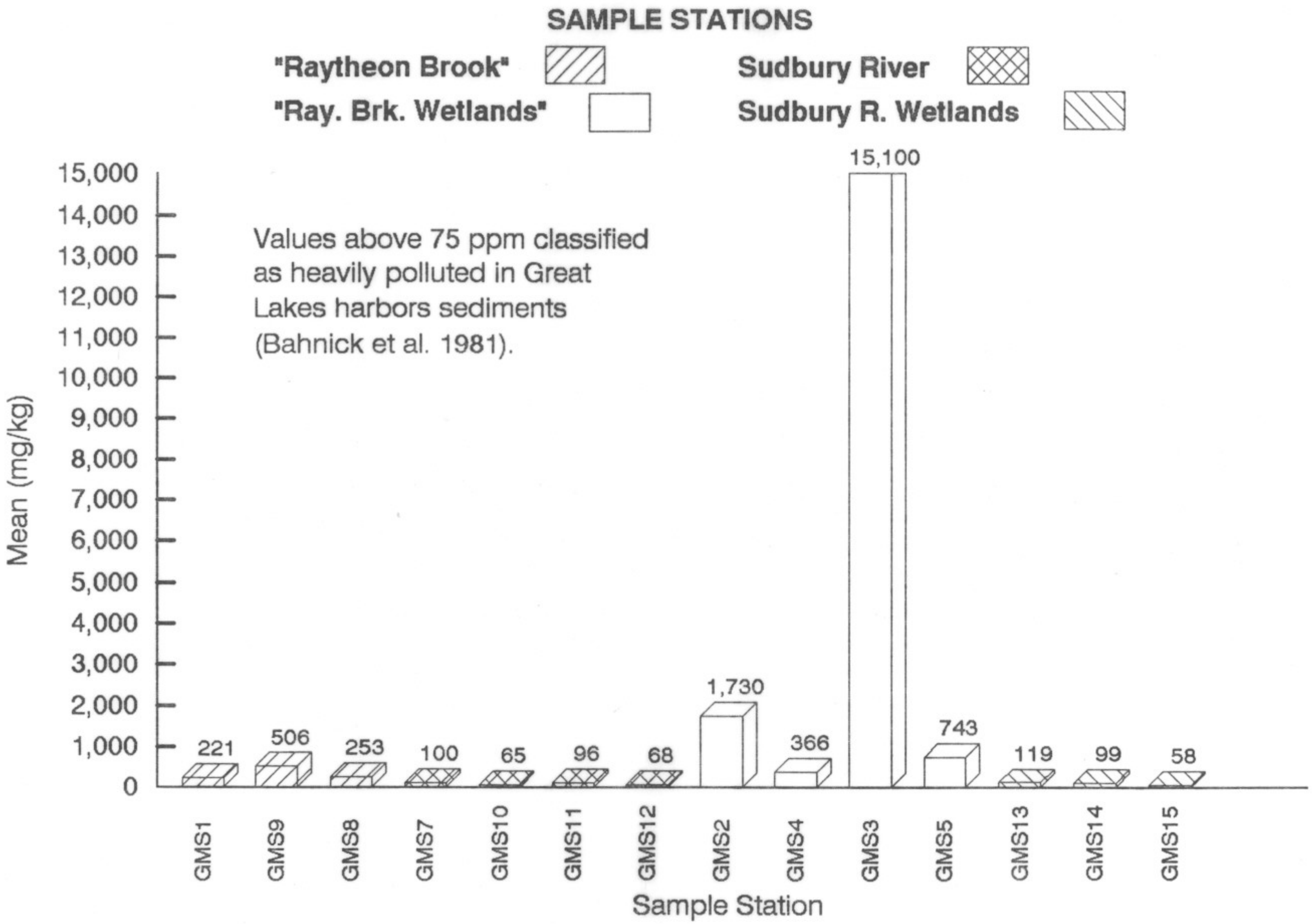


Fig. 25. Chromium in sediments (ppm DW) collected from the Sudbury River in 1989.

DISCUSSION

Summary of Trends Observed

Fish in both 1986 and 1987 harbored significant concentrations ($\geq$ 2.0 ppm) of PCBs in their tissues. Essentially, fish at all stations sampled down river of the Saxonville Dam, with the exception of the refuge impoundments, showed evidence of PCB contamination. Sediment samples collected in 1987 suggest that RAY1 (Raytheon Brook) is near a major source of PCBs. Sediment sampling in 1989 corroborated that the Raytheon Brook wetlands are contaminated with significant levels of PCBs. The results of the red-winged blackbird egg analyses suggest that the birds nesting in the vicinity of the Raytheon Brook wetlands carry a greater burden of PCBs than at other locations sampled. However, since red-winged blackbirds are migratory, and since notable PCB levels were detected in eggs at all of the stations, it is likely that some of the PCB burden in the red-winged blackbirds is attributable to general "background" accumulation from locations other than the Sudbury River. The small mammals analyzed were not found to harbor PCBs.

The fish sampling in 1986 and 1987 further indicated that some fish are also contaminated by dieldrin, and most of the fish samples contained small quantities of DDE. However, because dieldrin and DDE were not detected in the sediment samples, it is likely that these pesticides are ubiquitous in minute levels throughout the system and have bioaccumulated to detectable levels in the fish. Both dieldrin and DDE were also detected in the red-winged blackbird eggs, and the quantities of these pesticides appear to be correlated with that of the PCBs. Rohrer et al. (1982) also observed a correlation between the concentrations of PCBs and DDE in Great Lakes salmon, and attributed this to the chemicals' similar polarity and molecular size. However, since the birds are migratory, the source of the contamination may be from locations other than the Sudbury River.

Sediment sampling in 1987 also pointed to Raytheon Brook wetlands as a potential source area of PAHs. The 1989 sampling corroborated this finding with dramatically high levels of PAHs in the wetland sediments adjacent to "Raytheon Brook". According to Neff (1979), PAHs typically remain close to the site of deposition in aquatic environments. Our data appear to support Neff's assertion since the results of the 1987 fish, mammal, and bird egg sampling show that PAHs are not being incorporated riverwide in notable amounts in the food chain. Further, while PAH tissue residues in vertebrates are not reliable indicators of PAH contamination because they readily metabolize these compounds (Lawrence and Weber 1984), tissue residues, in conjunction with sediment data and the presence of melanomas in bullheads taken near Raytheon Brook, suggest that portions of the Sudbury River, and adjacent wetlands near Raytheon Brook, have been impacted by PAHs.

Heavy metals also were not found in fish in significant concentrations, although the levels of mercury, and potentially lead, may be approaching levels worthy of concern. Small mammals were found to harbor low levels of heavy metals, with slightly elevated levels of chromium and lead at some stations. Sediment sampling in 1987, however, indicated that heavy metals are distributed throughout the river system, and some notable trends are evident. Station SU2 had dramatically high concentrations of mercury relative to the other samples. Other heavy metals, including arsenic, lead, cadmium, and chromium were also found at elevated levels at SU2. These high levels may be attributable to the Nyanza Superfund site located a short distance upriver from Reservoir #2 (Yeaple and Feick 1973).

Station RAY1 also had consistently high levels of all metals. Exceptionally high levels of arsenic and lead were also found at the landfill site (station LF). However, arsenic and lead appear to be distributed throughout the river system. Stations SU10 and SU12 also appeared to harbor high levels of heavy metals relative to other locations in the river. Stations SU1 and WB1, which are located in the headwaters of the Sudbury River and Wash Brook, respectively, both had relatively low levels of all contaminants, and thus these stations may serve as examples of background levels for this region.

In reviewing the results of the sediment sampling from 1989, one trend is very clear. With the exceptions of arsenic and mercury, all of the contaminants were found in the highest concentrations in the wetlands adjacent to "Raytheon Brook" (stations GMS 2-5). These relationships seem to indicate that the source of these contaminants is located in the general locale of Raytheon Brook.

PCBs

PCBs, or polychlorinated biphenyls, are a group of halogenated aromatic hydrocarbons, which were used by industry from the late 1800's to the 1970's (Eisler 1986). PCBs are extremely stable compounds, which are relatively insoluble in water, and highly soluble in biological lipids (EPA 1980a). Due to their lipophilic nature, PCBs bioaccumulate in the food chain. Uptake of PCBs may be through direct contact (dermal sorption), from water through respiration, and through ingestion. Research indicates that diet is the primary route of exposure for most species of fish (Rubenstein et al. 1984). Studies have also shown that levels of contamination are directly related to duration of exposure (EPA 1980a), and that aquatic organisms which live in association with contaminated sediments are generally burdened with PCB levels that are equal to or greater than the sediment levels (Neff 1984). Bioaccumulation factors (BCFs) developed in a number of studies suggest that a bioaccumulation factor of 1.0 will likely underestimate the concentration in resident organisms. For example, Seelye *et al*. (1982) found a mean BCF of 2.7 for perch. NAS (1979) determined a BCF of 47.0 for *Daphnia magna* and 51.0 for crayfish (*Orconectes nais*).

Studies have shown evidence of chronic sublethal effects in aquatic organisms with low tissue concentrations. For instance, rainbow trout with a whole body concentration of 0.4 ppm FW were found to produce eggs with low survival (EPA 1980a). Rainbow trout eggs with a concentration of Arochlor 1254 of 0.33 ppm FW had high prehatch mortalities and deformed fry (Niimi 1983). Levels of 0.6 to 1.9 ppm FW in eggs and fry of Atlantic salmon (*Salmo salar*) were found to cause mortality of 46 to 100% (Niimi 1983). Reproductive failure in Cyprinid minnows was documented with PCB concentrations of 24.0 ppm FW (Bengtsson 1980).

Although Bahnick *et al*. (1981) considered sediment levels of 10.0 ppm indicative of heavily contaminated sediments, the literature discussed above suggests that much lower levels will cause adverse impacts to fish. This may also be exemplified in this study where PCBs were only detected at five stations, and four of the stations had levels between 1.0 and 1.5 ppm; yet a significant number of fish were found to harbor levels above 2.0 ppm FW. EPA (1980a) has suggested that fish whole body residues of <0.4 mg/kg FW would be protective of fishery resources. Based on effect levels documented in the scientific literature, the PCB levels found in many of the fish in our samples could be adversely affecting the health of these species.

Further, piscivorous predators are likely in danger of being affected by PCB contamination due to biomagnification. Mink (Mustela vison) are known to be very sensitive to PCBs (Eisler 1986). Fleming et al. (1983) found reproductive failure in ranch mink whose diets were contaminated with as little as 0.64 ppm PCBs. Black-crowned night herons (Nycticorax nycticorax) have been documented to have reduced hatching success and reduced survival of young with a geometric mean PCB concentration in eggs of 4.1 ppm (Hoffman et al. 1986). Mean PCB concentrations have also been found to be higher in the eggs of unsuccessful nests of bald eagles (Haliaeetus leucocephalus) (13.0 ppm) than in successful nests (7.2 ppm) (Weimeyer et al. 1984). However, PCB residues were closely correlated with DDE residues in this study. A more conclusive study with Forster's tern (Sterna forsteri) in Green Bay, Wisconsin found reproductive success to be significantly impaired by organochlorine contamination. Total PCB residues in whole eggs were found to range between 6.2 and 25.9 ppm (Kubiak et al. 1989). PCBs have also been suspected of causing bill defects in Forster's tern and other fish-eating birds (Gochfeld 1975; Gilbertson 1983; Kubiak et al. 1989).

However, some birds appear to be relatively resistant to PCB's (Eisler 1986). Concentrations in the brains of birds which died of PCB poisoning have been found in excess of 300 ppm (Stickel et al. 1984). Screech owls (Otus asio) fed a diet of 3.0 mg/kg of PCBs layed eggs with concentrations of up to 17.8 mg/kg FW, but no adverse effects were observed in parents or young (McLane and Hughes 1980). Chickens fed a diet of 5 mg/kg and mourning dove (Zenaidura macroura) fed a diet of 10 mg/kg showed evidence of reproductive impairment (Tori and Peterle 1983; Koval, Peterle, and Harder 1987). Although the PCB residues in the red-winged blackbird eggs found in this study, (6.0, 3.3, 2.0, and 1.5 ppm FW), are probably not high enough to cause reproductive problems in the birds, they are an indication that significant levels are in the food chain.

Small mammals have been documented to absorb PCBs from heavily contaminated sites (Batty et al. 1990). The fact that little was detected in small mammals in this study suggests that the heavily contaminated sediments are localized. Also, there is little evidence in the scientific literature that plants bioaccumulate PCBs in significant amounts from soil or sediment. Therefore, herbivorous mammals may not be expected to accumulate significant tissue concentrations of PCBs.

DDT

DDT is a broad spectrum insecticide which is toxic, persistent in the environment, and highly lipophilic. Because of these characteristics, DDT, and its metabolites bioaccumulate in the food chain. DDE is a common and stable metabolite of DDT that has primarily been associated with eggshell thinning in the literature (Ratcliff 1970; Longcore et al. 1971; Weimeyer et al. 1984; Grubb et al. 1990). Eggshell thinning has been held responsible for the threatened status of the bald eagle, peregrine falcon (Falco peregrinus), and osprey (Pandion haliaetus), as well as the population decline of many other bird species. Peakall et al. (1975) concluded from their own studies, and the literature, that 15-20 ppm FW was the critical level of DDE in bird eggs. Henny and Heron (1989) concluded that 4.0 ppm WW was the critical level for white-faced ibis (Plegadis chihi) eggs. The level found in red-winged blackbird eggs in this study were well below these critical levels ($\leq$ 1.0 ppm).

The FDA action level for total DDT in the edible portion of fish is 5.0 ppm for the protection of human health. The lowest permissible tissue concentration in prey fish based on reduced productivity of the brown pelican (Pelecanus occidentalis) is 0.15 mg/kg (Anderson 1975). Most of the levels found in fish in this study exceeded the 0.15 mg/kg threshold. However, the residues in fish found in this study are all comparable to those found in fish collected from 112 stations throughout the U.S. from 1976-1984 for the National Contaminant Biomonitoring Program (Schmitt et al. 1990). Based on the FDA action level for DDT, it can be concluded that the fish in the Sudbury River are relatively safe for human consumption. However, DDE could be a problem for some sensitive fish-eating birds along the Sudbury River as well as throughout the U.S.

DIELDRIN

Dieldrin and aldrin were widely used domestic pesticides which have been used primarily for corn pests and by the citrus industry (EPA 1980c). However, the registration for both materials have been cancelled in the U.S., except for termite control. Aldrin is metabolically transformed to the more stable dieldrin in the environment. Dieldrin is highly persistent, has low solubility in water, and high affinity for fat, and thus bioaccumulates in the food chain. Dieldrin has been associated with direct mortality of birds rather than reproductive failure. Levels of dieldrin in the brain's of pen-reared pheasants which were fed lethal levels of dieldrin, ranged from 1.15 ppm to 26.7 ppm (Baxter et al. 1969). Stickel et al. (1969) concluded that 4.0 ppm of dieldrin in the brain of birds is the lower lethal level. Weimeyer et al. (1975) concluded that dieldrin increased mortality of osprey in Connecticut, and thus contributed to the population decline in that state. Dieldrin poisoning has also been documented in bald eagles (Reichel et al. 1969).

Dieldrin is considered to be acutely toxic to all life forms, and there is some evidence of carcinogenicity in mammals (EPA 1980c). In this study, residues in **whole** yellow perch slightly exceeded the FDA action level for the **edible portion** of 0.3 ppm at one station (SU4). In general, levels in yellow perch appear to have slightly exceeded the levels found by the National Contaminant Biomonitoring Program for stations throughout the U.S. from 1976 to 1984 (Schmitt et al. 1990). These data suggest that dieldrin, in some locations in the Sudbury River, has the **potential** of bioaccumulating to near the FDA action levels, and may warrant further monitoring. However, the highest levels found in our survey (0.32 ppm in yellow perch) do not approach the dietary effect levels for most bird species (Hudson et al. 1984). The source of the dieldrin appears to be upriver of SU3 (Table 8; Fig. 16), possibly in the Framingham area. The continued use of dieldrin for termite control might explain its relatively elevated concentration in fish downstream of Framingham.

PAHs

Polynuclear aromatic hydrocarbons (PAHs) are a group of compounds which are formed from the incomplete combustion of organic material. Many of the compounds are highly carcinogenic. Major sources of PAHs in the environment include forest fires and combustion of fossil fuels. PAHs are transported into aquatic environments through rainfall, surface runoff, effluent discharges, and petroleum spills (Eisler 1987).

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PAHs are persistent in the environment, and degrade slowly, particularly when they are associated with aquatic sediments due to a lack of oxygen and light (Neff 1979). PAHs are absorbed by living organisms through dermal contact, inhalation, or ingestion. The toxicity of PAHs varies, depending greatly on the molecular weight of the PAH compound, and the tolerance of the organism (Eisler 1987). Crustaceans are particularly vulnerable to PAH toxicity (Neff 1979), possibly because they lack enzymes capable of metabolizing PAH compounds (Varanasi et al. 1985). Although vertebrates and microorganisms are able to metabolize PAHs, sometimes to a point of complete degradation, there is evidence that chronic exposure to PAHs is linked to an increased incidence of cancer in fish and mammals (EPA 1980; Neff 1982). Information on the sublethal effects of PAHs is limited, although, research by Payne et al. (1988) demonstrated a biological response by winter flounder (Pseudopleuronectes americanus) to sediments contaminated by as little as 1.0 ppm of PAHs. Although literature on the response of birds to PAHs is also limited, increased embryotoxicity has been demonstrated by both external application and injection of PAHs to avian eggs (Hoffman and Gay 1981; Brunstrom et al. 1990).

Due to the complexity of evaluating the response of organisms to the many PAH compounds, guidelines for the protection of fish and wildlife, have not yet been developed. However, the literature suggests that some of the PAH levels found in the Sudbury River are of potential concern, and the levels at the Raytheon Brook wetlands are particularly alarming. Apparent effect levels of total PAHs in **marine** sediments have been reported to adversely affect bivalve larvae at concentrations as low as 0.87 ppm (Long and Morgan 1990). However, the same authors list the median effect concentration for sediment-borne total PAHs in marine systems as 35.0 ppm. While only the Raytheon Brook site has total PAHs exceeding the 35.0 ppm median effects level, all sample stations have total PAHs sediment concentrations exceeding the 0.87 ppm effect level reported for marine bivalve larvae. Therefore, if portions of freshwater ecosystems are as sensitive as the more sensitive portions of marine systems, portions of the biological community in the Sudbury River could be adversely impacted by the sediment burdens of total PAHs.

There is also circumstantial evidence that some local effects of PAHs are being expressed in Sudbury River bullheads. Our fish sampling in the area of Rte. 20 (SU5&6), Fairhaven Bay (SU9), and the Sudbury-Assabet confluence (AS1, CO2), produced bullheads with invasive melanomas typically associated with exposure to carcinogenic PAHs. While it is not possible from our data to definitively prove that PAHs are responsible for melanomas in Sudbury River bullheads, we believe they are most likely the agents responsible.

MERCURY

Mercury is a known toxin, mutagen, teratogen, and carcinogen. Sources of mercury include both natural and anthropogenic. Anthropogenic sources include combustion of fossil fuels, antifouling paints, agricultural pesticides, disposal of batteries, and pulp and paper mill residues (Eisler 1987b). Although methylmercury is the most toxic form, microorganisms can convert any form of mercury to methylmercury. Therefore, all forms of mercury are hazardous to the environment (EPA 1980e).

Sublethal effects in organisms have been documented at relatively low concentrations of mercury. Reduced growth of sensitive aquatic organisms has been documented at water concentrations of 0.04 to 1.0 ug/l (Eisler 1987b). In birds, mercury residues in eggs of 0.79 to 2.0 mg/kg have been found to impair reproduction (Eisler 1987b).

Lethal toxicity of mercury depends on many factors, including the form of the mercury, species, sex, age of the organism, and whether other contaminants are present, such as lead, DDE, or parathion (Fimreite 1979). Acute oral toxicity for most bird species occurs when diets contain between 2.2 and 31.0 mg of mercury per kg of body weight (Eisler 1987b). Mercury residues in fish (whole body) that died of mercury poisoning ranged from 5.0 to 7.0 ppm (Armstrong 1979). For mammals, death occurred after a daily intake of 0.1 to 0.5 mg of mercury per kg of body weight (Eisler 1987b).

The results of studies which have attempted to document biomagnification of mercury have been inconsistent (Kay 1984). However, at least 2 studies have reported higher levels of mercury in the top predatory fish than in fish at lower trophic levels (Fimreite and Reynolds 1973; May and McKinney 1981).

The Massachusetts Division of Water Pollution Control (DEP) sampled fish in the Sudbury River in 1985, 1986, 1987, and 1988 to determine levels of heavy metals in the edible fillets (Maietta Memo to Johnson, Appendix 10). Sampling in 1985 found a substantial number of fish with mercury residues which exceeded the FDA action level of 1.0 ppm. As a result, the Sudbury River was posted advising anglers not to eat the fish. In 1986, fish were sampled from Heard Pond, and again some fish were found to carry elevated levels of mercury. In 1987, Heard Pond was also posted. In 1986 and 1987, the mainstem of the river was again sampled, but none of the fish were found to be burdened with elevated levels of mercury, except for predatory fish in Reservoir #1. Due to the inconsistency in the data between 1985 and 1986/1987, the mainstem of the river was again sampled in 1988. The 1988 sampling of top trophic level fish corroborated the 1985 results that mercury in the fish from the lower Sudbury and upper Concord Rivers was a threat to human consumers.

In our study, none of the fish sampled were found to carry excessively elevated levels of mercury (mean level equaled 0.32 mg/kg). However, none of the fish sampled in the mainstem of the rivers were top level predators. Further, the mean residue level of fish collected in our study notably exceeds the geometric mean for mercury concentration of 0.10 mg/kg found in fish collected from 109 stations across the U.S. for the National Contaminant Biomonitoring Program (Schmitt and Brumbaugh 1990). Although the levels of mercury in fish in the Sudbury River are well below levels found to cause acute toxicity in birds and fish, it is within the lethal dose for mammals, and it is plausible that the mercury could biomagnify in the system to a degree that could threaten piscivorous birds or fish.

LEAD

Lead is a cumulative metabolic poison, that exists in the environment due to both natural and anthropogenic activities. Natural lead leached from ores, however, is not usually mobile in ground or surface water as it tends to bind with other compounds (EPA 1980e). Anthropogenic sources of lead typically reach the aquatic environment through precipitation, fallout of lead dust, street runoff, and industrial and municipal discharges (EPA 1980e). Once in the aquatic environment, the lead is typically incorporated into bottom sediments (Harrison and Laxen 1981). Lead is usually absorbed by fish and wildlife through ingestion. However, there is little evidence that lead biomagnifies in the food chain, hence, it is typically the older animals from contaminated environments that are burdened the most with lead residues (Eisler 1988).

Since lead is a naturally occurring element, it was present in all sediment samples collected in our study. However, the primary anthropogenic sources of the lead are probably road runoff, agricultural pesticides (lead arsenate), leachate from landfills, and possibly industrial effluent. Although in aquatic environments, it is the dissolved lead that is the most toxic to organisms (Wong _et_ _al_. 1978), there is some evidence that lead in sediments may be taken up by aquatic plants and benthic organisms (Fowler 1977). Also, lead is known to be more mobile in lower pH waters (Demayo et al. 1982).

Although the overall dangers of lead-contaminated sediments to aquatic life are not yet clear, a few studies evaluating sediment effects reported that aquatic invertebrates exposed to lead contaminated sediments exhibited a toxic response. Tatem _et_ _al_. (1986) observed significant mortality to prawn (_Macrobrachium_ _rosenbergii_) when exposed to lead levels in sediments of 253 ± 47 ppm. Maleug _et_ _al_. (1984) found sediment lead levels of 110.0 ppm to cause significant mortality to _Daphnia_ _magna_. In our study, lead levels in sediments ranged from 56.0 to 360.0 ppm.

The mean concentration of lead in all the fish sampled in this study was 0.37 ppm, which is notably higher than 0.10 ppm which was the geometric mean of lead residues measured in fish collected in the National Contaminant Biomonitoring Program from 1976-1984 (Schmitt and Brumbaugh 1990).
Since lead that is absorbed by the body typically accumulates in hard tissues such as bone and teeth (Eisler 1984), much of the residues measured in fish collected in this study are probably associated with portions of fish which are considered inedible to humans. However, animal consumers of fish, such as fish-eating birds, would be exposed to most of the lead in fish tissues. A study by Hoffman _et_ _al_. (1985) fed lead to nestling American kestrel (_Falco_ _sparverius_) and found that 40% of the nestlings died after ingesting 625 mg/kg of lead for six days. Adult kestrels fed 50 mg of lead per kg of body weight, however, have not been found to be significantly affected (Franson _et_ _al_. 1983; Pattee 1984). Lead concentrations of 860 ppm have been found to cause significant mortality in red-winged blackbirds. In the same study, 50% of the screech owls tested died after being fed 23,100 ppm of lead (Beyer _et_ _al_. 1988). Based on these values, it appears that it is unlikely that the lead in the Sudbury River fish represents a dietary hazard to fish-eating wildlife.

ARSENIC, CADMIUM, AND CHROMIUM

There is little evidence that arsenic, cadmium, or chromium biomagnify in the food chain (Kay 1984), however, all are toxic to aquatic life at high levels in water or tissue. All of the these metals are naturally ubiquitous in low concentrations. High levels are usually the result of anthropogenic discharges. A common anthropogenic source of arsenic is the agricultural runoff of pesticides. Arsenic is also used in wood preservatives and growth stimulants for plants and animals (Eisler 1988). The presence of cadmium and chromium in high levels in the environment is typically due to industrial and municipal effluents (Eisler 1985; Eisler 1986b). Although none of these metals were found in animal tissue at alarming levels in this study, their presence and their distribution in the sediments provide clues as to the sources and extent of pollution in the river system.

Arsenic is absorbed by organisms through ingestion, inhalation, or permeation through the skin. However, its toxicity and bioavailability depends on its chemical state. For instance, inorganic arsenicals are more toxic than organic arsenicals, and under some aquatic conditions, arsenates are bound to organic sediments (EPA 1980f). In vertebrates, arsenic is readily absorbed after ingestion, and is usually excreted in urine within a few days, therefore, arsenic poisoning is typically either acute or subacute, rather than chronic. Some aquatic species have been reported to be adversely affected when they carried body tissue burdens of 1.3 to 5.0 mg/kg. Sensitive species of birds died after receiving a single oral dose of 17.4 to 47.6 mg of arsenic per kg of body weight. Adverse effects to mammals have been reported after a single oral dose of 2.5 to 33 mg of arsenic per kg of body weight (EPA 1985).

The mean level of arsenic in the fish collected in this study was 0.06 ppm. The geometric mean of arsenic in fish collected across the U.S. in the National Biomonitoring Program was 0.14 ppm (Schmitt and Brumbaugh 1990). This information indicates that although the level of arsenic in the sediments appears elevated, it is not being absorbed in significant amounts by the food chain.

Cadmium is readily adsorbed to clay and organic sediments which limits is bioavailability in aquatic environments (Gardiner 1974). Freshwater biota are considered the most sensitive to cadmium poisoning. Freshwater insects, crustaceans, and fish have exhibited significant mortality with cadmium concentrations of 0.8 to 9.9 ppb. Birds and mammals appear to be relatively resistant to cadmium (Eisler 1985). For example, sublethal effects were observed in mallard ducklings (Anas platyrhynchos) after being fed 20 ppm cadmium for 12 weeks (Cain et al. 1983). Adult mallards have been fed up to 200 ppm for 90 days without mortality or loss of weight (White and Finley 1978). The lowest dose of cadmium that produced death in mammals was 250 mg/kg of body weight for rats and 150 mg/kg in guinea pigs (EPA 1980g).

In our study, the cadmium levels in sediments ranged from 0.84 to 14.00 ppm. The total mean level of cadmium residues in the fish found in our study was 0.03 ppm, which is equal to the geometric mean for cadmium found in fish across the U.S. in the National Contaminant Biomonitoring Program (Schmitt and Brumbaugh 1990). It, therefore, appears that the cadmium levels in the Sudbury River fish are well below levels of concern.

Chromium exists in the environment in a number of different chemical states, which makes it difficult to analyze the effects of various concentrations of chromium in the environment on the organisms living there. Similar to cadmium, chromium bonds readily to organic sediments rendering most of it biologically unavailable. However, some environmental factors such as pH, temperature, and salinity, can increase or decrease its bioavailability (Eisler 1986b). Cr+6 is the form that is most toxic to aquatic life, and can cause a reduction of growth and inhibit reproduction (Van der Putte et al. 1981). However, it is difficult to quantify the different chemical species or ionic states in a chromium sample. In Eisler's (1986b) review of the literature, he suggests that fish and wildlife tissues which contain >4.0 mg/kg of chromium is evidence of contamination. In our study, the small mammal samples collected from stations SU7 and WB1 contained levels far exceeding 4.0 mg/kg. Meadow mice collected from SU7 contained 67.1 ppm WW, and meadow jumping mice collected at WB1 contained 91.44 ppm WW. The sources of the chromium contamination are unclear.

CONCLUSIONS

Based on the distribution of contaminants in the river sediments, (particularly PCBs, PAHs, mercury, lead, cadmium, and chromium), there appear to be several major sources of pollution within the study area. One of these is the Nyanza Superfund site, which is known to have introduced mercury into the Sudbury River. The high sediment mercury levels in Reservoir #2, just downstream of the Nyanza site are likely attributable to mercury released from this site. A second source area appears to be in the locale of the Raytheon Brook wetlands. Heavy metals, (particularly mercury, lead, and arsenic), are also distributed at elevated levels, in comparison to other sediment criteria, throughout the river systems which suggests present and/or historical nonpoint discharges of pollutants. However, based on the levels measured in biota, the biological impact of the heavy metals in the sediments, (particularly lead, arsenic, cadmium, and chromium), is unclear.

Concentrations of PCBs and PAHs in sediments in the vicinity of the Raytheon site are high and should receive additional attention. The overall PCB and PAH concentrations for the Sudbury River do not appear to represent a significant hazard to piscivorous birds, but could adversely affect highly susceptible mammals, such as mink. No other organochlorine pesticides surveyed in our study appear to represent significant hazards to the Sudbury River biota.

The potential effects of mercury on the Sudbury River biota are unclear. Our data show mercury levels (in mid-level consumer, whole fish) to generally be below effect levels to fish or piscivorous predators. However, mercury residues in fillets of top-level predatory fish, as reported by MADWPC (DEP), show mercury levels with the **potential** to affect piscivorous birds. It is likely that the disparity in mercury levels between our surveys and the MADWPC's (DEP) surveys is due to the analyses of different tissues (i.e., whole fish vs. fillets). Since fish-eating birds typically consume the whole fish, we assume that dietary exposure to mercury, through the aquatic food chain, is not a significant, detrimental factor for birds using the Sudbury River.

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Apendices which include the raw data and QA/QC results are available upon request from the Concord, NH Field Office.

66 pgs.

Fish & Wildlife Manuals

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"	<00195002.gif>	5 (Fig. 2)
"	<00195003.gif>	6 (Fig. 2) (CONT.)
"	<00195004.gif>	7 (Fig 2) (CONT.)
"	<00195005.gif>	8 (Fig. 3)
"	<00195006.gif>	12 (Fig. 4)
"	<00195007.gif>	14 (Fig. 5)
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L.C. mp.

Conv 5

Author: Charlie Chandler at 9AR~FWE1
Date: 6/10/98 2:09 PM
Priority: Normal
TO: Tim Fannin at 5HA~MAIN2
Subject: Final Report correction

--------------------------- Message Contents ---------------------------

Howdy!

You sent the report "Contaminat Levels in the Sudbury River, Massachusetts. (6/91)". It arrived with a cover memo dated 5/15/98. The project number you referenced was R5-86-009. The number is probably accurate, but my database does not go that far back.

We do already have a copy which completes project 89-5-103/8950003 for the Concord FO. Just thought you might want to synchronize our respective files. Take care.

Charlie

Vicki,
This should be a duplicate, but need to confirm.
Charlie

United States Department of the Interior

FISH AND WILDLIFE SERVICE
300 WESTGATE CENTER DRIVE
HADLEY, MA 01035-9589

In Reply Refer To:
FWS/Region 5/ES-EC

MAY 15 1998

Memorandum

To: Chief, Division of Environmental Contaminants

From: Environmental Contaminants Coordinator

Subject: Final Completion Report - Contaminant levels in the Sudbury River: Massachusetts

The final report for Off Refuge investigation project R5-86-009 has been received in the Regional Office. The accession title for the report is: **"Contaminant levels in the Sudbury River: Massachusetts"**, by Laura Eaton and K.C. Carr. The Region 5 Environmental Contaminants Coordinator is pleased to provide you with a copy.

As always, we welcome the opportunity to document the effectiveness and ingenuity of the Region 5 Field Contaminants Specialists. This report is an indicator of the level of imagination, effort, and perseverance invested in these studies, and reveals the extensive contributions made by the Environmental Contaminants Specialists in providing assistance to other Service programs, preventing injury to our resources, and giving early warning of impending problems in Region 5! We provide you the information in the report, and underline the need for similar investigations, as a stimulus for you to secure expanded Service funding for these important studies.

If you have any further questions or need additional information, please call Tim Fannin at (413) 253-8646.

Attachment